ASSESSMENT OF CLIMATE CHANGE AND ASSESSMENT OF WATER QUANTITY THREATS IN THE IPZ-Q IN SUPPORT OF THE GUELPH-GUELPH/ERAMOSA WATER QUANTITY POLICY STUDY

Report Prepared for:
LAKE ERIE SOURCE PROTECTION REGION

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WATER QUANTITY POLICY DEVELOPMENT STUDY

Report prepared for Lake Erie Source Protection Region, November 2018

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1 INTRODUCTION

The Province of Ontario introduced the *Clean Water Act, 2006* (Bill 43; Government of Ontario 2018) to ensure that all residents have access to safe drinking water. The City of Guelph and Township of Guelph/Eramosa (GGET) lie within the Grand River Source Protection Area (watershed), which, along with the Long Point Region, Catfish Creek, and Kettle Creek Source Protection areas, are part of the larger Lake Erie Source Protection Region. The Lake Erie Region Source Protection Committee (SPC) was established in 2007 and has the responsibility under the *Clean Water Act, 2006* to develop local Source Protection Plans (SPPs) and report on implementation in all four watersheds. The goal of each SPP is to develop policies and programs to eliminate, reduce, and/or manage existing Significant Drinking Water Threats (i.e., water quality and water quantity threats) and ensure no future drinking water threats become Significant. These policies might relate to activities in identified groundwater vulnerable areas (e.g., Wellhead Protection Areas for Water Quantity [WHPA-Qs]) and/or surface water vulnerable areas (e.g., Intake Protection Zones for Water Quantity [IPZ-Qs]) and might include public education programs, or programs to promote best management practices. Current approved SPPs address threats related to water quality. A Risk Management Measures Evaluation Process (RMMEP) was completed in 2018 (Matrix 2018) as part of a larger Water Quantity Policy Development Study for the GGET municipal water supply systems and represented a major piece of work to complete the water quantity component of SPPs.

The specific goals of the RMMEP for the GGET municipal water supply systems were to:

- Identify and rank the Significant Threats to water quantity within the WHPA-Q that surrounds the City of Guelph. The WHPA-Q was assigned a Significant Risk Level during the City of Guelph and Township of Guelph/Eramosa Tier Three Water Budget and Local Area Risk Assessment (Matrix 2017).

- Select and evaluate multiple risk management measures that have the potential to reduce the risk to water quantity.

- Develop a Threats Management Strategy that summarizes the risk management measures that are predicted to be most effective at reducing the risk to municipal wells and provide recommendations on how these measures can be implemented and tested.

The RMMEP focused on the assessment of the Significant Threats to groundwater water quantity within the WHPA-Q; however, Significant Threats also exist to surface water quantity within the IPZ-Q. The potential impact of climate change as a threat to the quantity of municipal water supplies in GGET was also not evaluated as part of the initial components of the RMMEP.

The *Technical Rules: Assessment Report, Clean Water Act, 2006* (Technical Rules; MOECC 2017), do not specifically require that climate change assessments be completed. However, the rules do require that assessment reports identify the effects that projected changes in the climate over the following 25 years will have on the conclusions reached in the Assessment Report and a list of the information sources underlying those projected changes.

This report summarizes an assessment of the relative impact of climate change as a possible threat to water quantity and also provides an evaluation of Significant Threats within the IPZ-Q. It supplements the work conducted for the RMMEP as documented in Matrix (2018), and that report should be referenced for a more fulsome summary of the RMMEP process.

1.1 Water Budget Studies in the Grand River Watershed and City of Guelph and Township of Guelph/Eramosa Area

The *Clean Water Act, 2006* requires that each SPC prepare an Assessment Report for their source protection area in accordance with Ontario Regulation 287/07 (Government of Ontario 2018) and the Technical Rules (MOECC 2017) requirement of the Assessment Report is the development of water budgets that assess the threats to water quantity sources under a tiered framework. Tier One and Tier Two Water Budget and Stress Assessments (Tier One Assessment and Tier Two Assessment) of this framework evaluate a subwatershed's hydrological stresses, while a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) identifies threats to water quantity and evaluates the ability of a community's wells and intakes to meet current and future drinking water needs.

1.1.1 Grand River Watershed Water Budget and Tier Two Water Quantity Stress Assessment

A Tier Two Assessment was completed for the Grand River Watershed in 2009 (AquaResource 2009a, 2009b). The study identified subwatersheds and groundwater assessment areas that contain municipal water supply systems that had an elevated (Moderate or Significant) potential for hydrologic stress from a surface water or groundwater perspective. This included the Upper Eramosa River Subwatershed and the Upper Speed River Assessment Area, which were classified in the Tier Two Assessment as having a Moderate stress level from a surface water and groundwater perspective, respectively. Some of the municipal water supplies for the City of Guelph, as well as Rockwood and Hamilton Drive in the Township of Guelph/Eramosa (Figure 1), were contained within these areas and were therefore required to undertake a Tier Three Assessment (Matrix 2017).

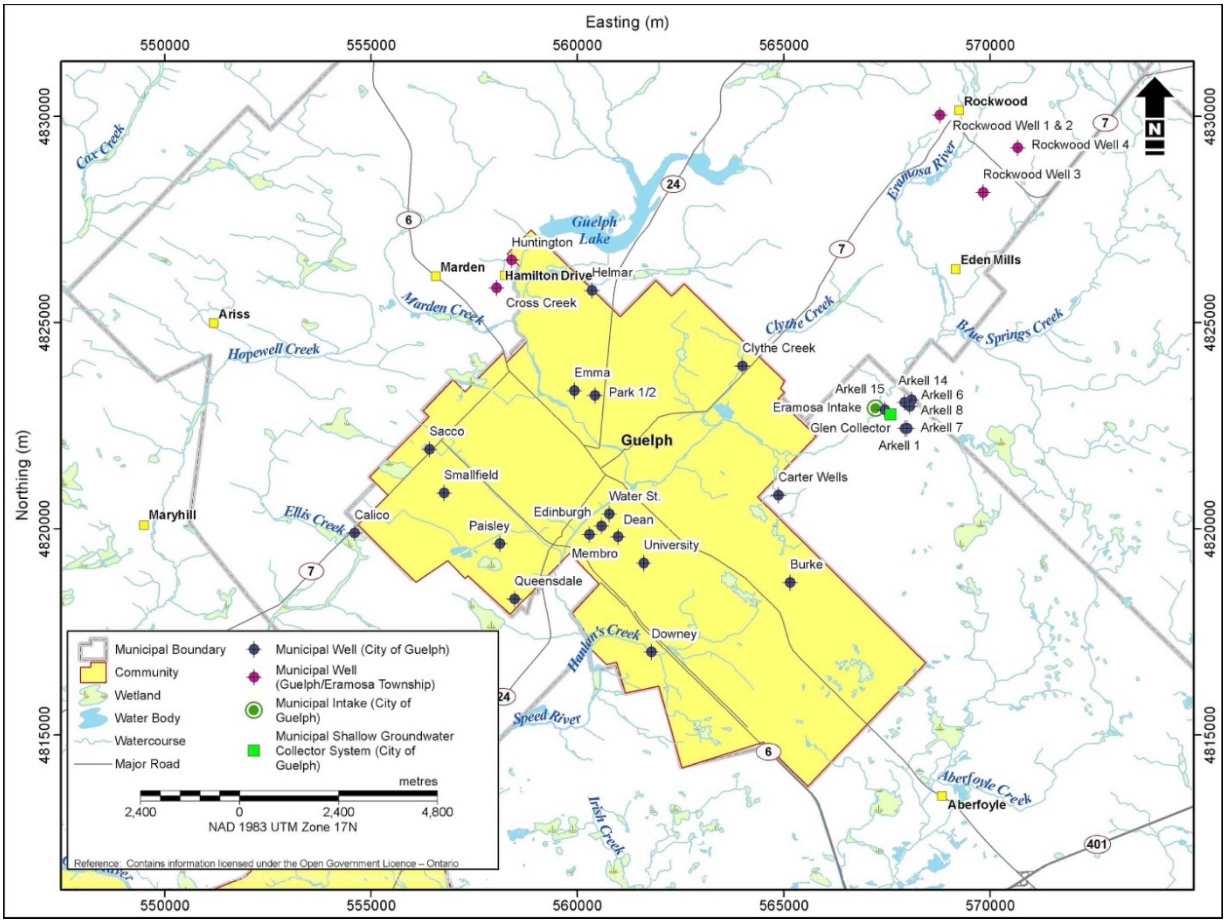

FIGURE 1 Tier Three Assessment Municipal Water Supply Systems

1.1.2 City of Guelph and Township of Guelph/Eramosa Tier Three Water Budget and Local Area Risk Assessment

A Tier Three Assessment evaluates the ability of municipal water supply systems to meet current and future demands, as well as impacts to other water uses under conditions set out in the Technical Rules. If the Tier Three Assessment results in conditions where municipal wells cannot meet their demands, or if there is an impact on other water uses (e.g., coldwater streams), activities resulting in consumptive water use or groundwater recharge reduction may be classified as Moderate or Significant Drinking Water Quantity Threats (Significant Threats). Consumptive water use refers to the amount of water removed from a source without being returned to the same source. The following sections describe the Tier Three Assessment carried out for the GGET water supply systems.

1.1.2.1 Municipal Water Supply Systems

Thirty-one municipal wells, a surface water intake that feeds water to an artificial recharge system, and a shallow groundwater collector were assessed as part of the GGET Tier Three Assessment.

City of Guelph

The City of Guelph relies mainly on groundwater for its municipal supply demands, and it obtains its water from 25 municipal wells and a shallow infiltration gallery (Glen Collector; Figure 1); however, not all of the wells are used where there are periods of lower demand or where there are water quality concerns. All of these wells, with the exception of the Edinburgh well, were used in the Tier Three Assessment and RMMEP to meet future demands.

The City of Guelph also sources a portion of its water supply from the Eramosa River intake, where surface water is pumped and then directed into the Arkell artificial recharge system that provides shallow groundwater to the Glen Collector (Figure 1). The Glen Collector is a series of perforated pipes in the overburden that collects water that has recharged the subsurface naturally (e.g., on the Paris Moraine) and also water that has entered the subsurface through the artificial recharge system. While water pumped from the Eramosa intake is not fed directly into the drinking water system, the sustainability of the municipal water supply relies on the Glen Collector and the interconnection between it and the supply available from the Eramosa River. The Eramosa River intake is allowed to operate between April 15 and November 15 of each year according to the conditions of its Permit to Take Water (PTTW).

Township of Guelph/Eramosa

The residents of Rockwood and Hamilton Drive rely entirely on groundwater for their potable water supplies. In Rockwood, this water is pumped from three existing bedrock wells. A fourth bedrock well was recently constructed by the Township of Guelph/Eramosa and now has a PTTW. The township expects to add this well to the Rockwood water supply system in the near future. These wells are located northeast of the City of Guelph (Figure 1).

In Hamilton Drive, municipal water is pumped from two bedrock wells completed in the same bedrock aquifer as Rockwood and the City of Guelph. These wells are located just north of the City's municipal boundary (Figure 1).

1.1.2.2 Tier Three Assessment Water Budget

The GGET Tier Three Assessment was completed in March 2017 (Matrix 2017) following the Province's Technical Rules (MOECC 2017), *Technical Bulletin: Part IX Local Area Risk Level* (Technical Bulletin; MOE and MNR 2010), and the *Memorandum: Assignment of Water Quantity Risk based on the Evaluation of Impacts to Other Water Users* (Technical Guidance Memorandum; MOE 2013). As part of the Tier Three Assessment, surface water and groundwater numerical models were developed, calibrated, and applied to help evaluate the sustainability of the municipal water supplies of GGET. The models developed helped quantify a water budget for the municipal supplies, including estimates of the magnitude of water entering and leaving the system.

The models were also used to delineate the WHPA-Q and IPZ-Q where the municipal drinking water systems could be affected by other existing, new, or expanded water takings. The WHPA-Q was defined as the combined area that is the cone of influence of a municipal well and the whole of the cones of influence of all other wells that intersect that area, plus any area where a future reduction in recharge may have a measureable impact on the cone of influence (MOECC 2017). The IPZ-Q was defined as the drainage area that contributes surface water to the intake and the area that provides recharge to aquifers that contribute groundwater discharge to the drainage area. Four WHPA-Qs were delineated surrounding the municipal wells for GGET (Figure 2); one IPZ-Q was delineated as the upstream contributing area for the Eramosa intake (Figure 3).

The WHPA-Q-A extends to the southwest, toward the City of Cambridge, where it overlaps with the WHPA-Q developed as part of the Region of Waterloo Tier Three Assessment (the Region; Matrix and SSPA 2014). This overlap is described in more detail in Appendix H of Matrix (2017). The hatched area of Figure 2 represents where the Region of Waterloo Tier Three Assessment (Matrix and SSPA 2014) should be referenced for additional details regarding WHPA-Q delineation in that area.

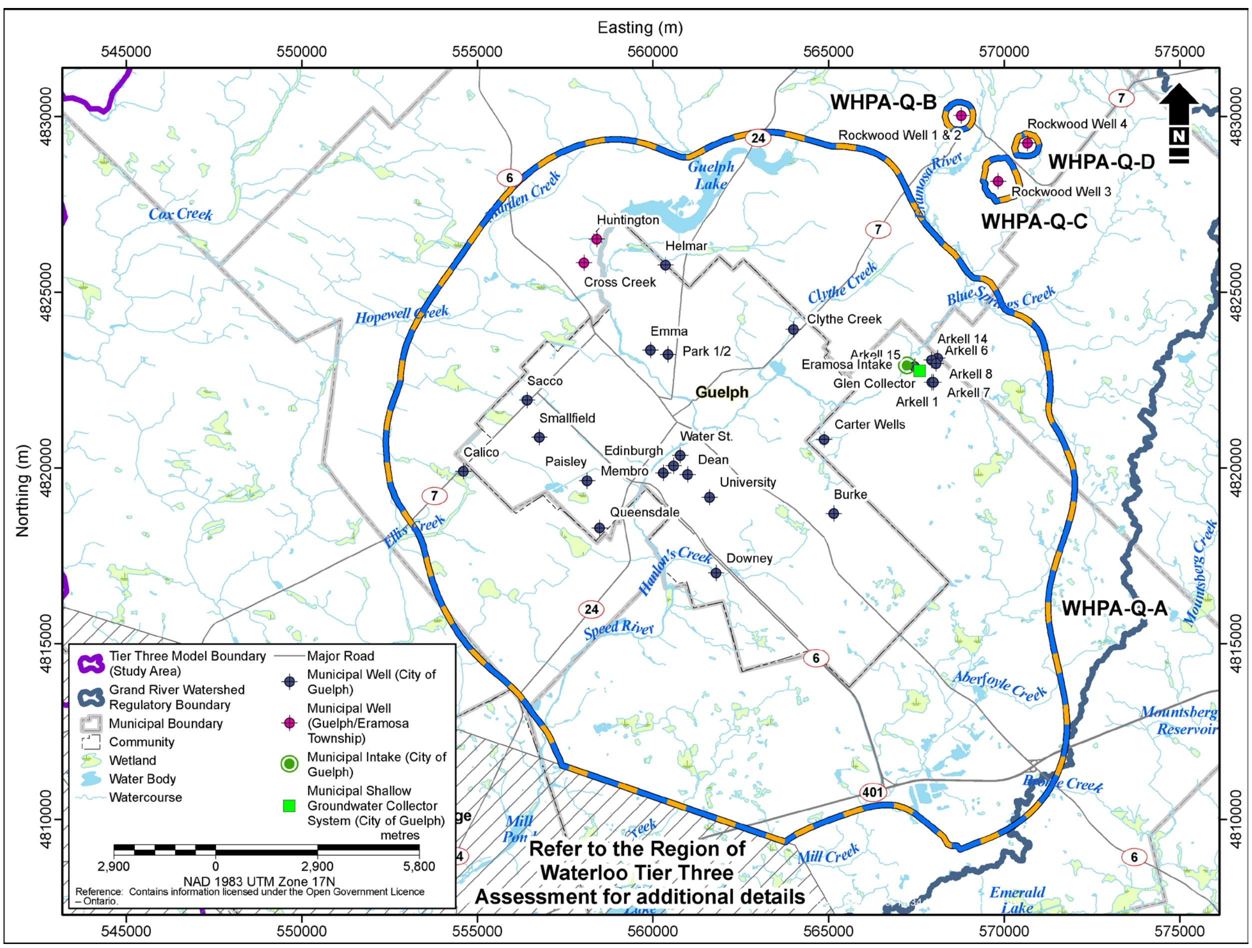

FIGURE 2 WHPA-Qs Delineated in Tier Three Assessment (Matrix 2017)

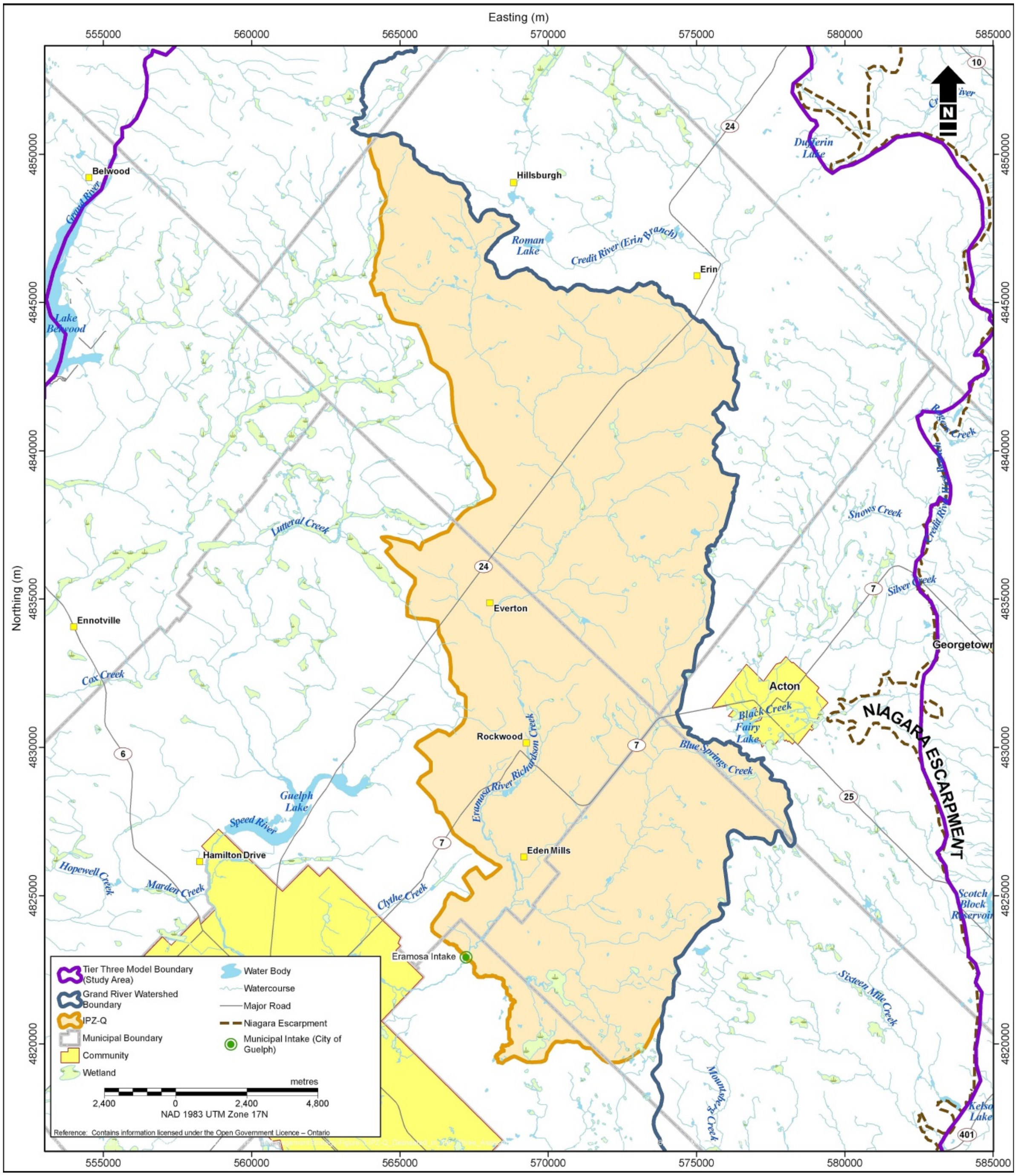

FIGURE 3 IPZ-Q Delineated in Tier Three Assessment (Matrix 2017)

1.1.2.3 Tier Three Assessment of Water Quantity Threats

The final task of the Tier Three Assessment was to assign a Risk Level to the WHPA-Qs and IPZ-Q, and identify water quantity threats. The Tier Three Assessment scenarios predicted that the GGET municipal wells can meet current water demands; however, the Tier Three model scenarios predicted that the City's Queensdale municipal well may not be able to meet future needs under normal climate conditions and during prolonged drought. The City's other wells and Guelph/Eramosa Township's wells were expected to meet future needs under all scenarios. However, there is a high level of uncertainty for the results of the City's Arkell Well 1, which also triggers a Significant Risk Level. Because of these findings, the WHPA-Q surrounding the City of Guelph (WHPA-Q-A; Figure 2) was assigned a Significant Risk Level; the other three smaller WHPA-Q areas (WHPA-Q-B/C/D) were assigned a Low Risk Level (Figure 2).

A Risk Assessment for the Eramosa River surface water intake supply was not completed earlier because water pumped from the Eramosa River is not pumped directly into the City of Guelph's drinking water system. Instead, this water enters the shallow overburden through the Arkell artificial recharge system and a portion of this water is captured by the Glen Collector. To ensure the sustainability of the Glen Collector and the Eramosa intake, the IPZ-Q was assigned the same Risk Level as the WHPA-Q, containing the Glen Collector. For the remainder of this report, WHPA-Q-A will be referred to as WHPA-Q. More details on the delineation of the WHPA-Q and the Significant Risk designation are provided in the Tier Three Assessment (Matrix 2017).

The Tier Three Assessment also predicted that groundwater discharge into some coldwater streams may be reduced by 10% or more as municipal pumping is increased to future rates. According to the Technical Rules (MOECC 2017), where existing takings are increased, this magnitude of impact would result in a Moderate Risk Level applied to the WHPA-Q; however, the Moderate Risk Level associated with the surface water impacts is superseded by the Significant Risk Level.

Under the source protection program (Section 1.1 of Ontario Regulation 287/07), the Province identified 22 activities that are prescribed as drinking water threat activities. For water quantity vulnerable areas with a Significant Risk Level, all existing and new consumptive water takings (i.e., prescribed drinking water threat #19) located within the areas that draw water from within the WHPA-Q or the IPZ-Q or activities that reduce groundwater recharge (i.e., prescribed drinking water threat #20) are classified as Significant Threats. Within the Tier Three Assessment WHPA-Q (Figure 4) and IPZ-Q (Figure 5), the Significant Threats included the following:

- municipal permitted water takings
- non-municipal permitted water takings
- non-municipal, non-permitted water takings (e.g., domestic takings)
- recharge reduction activities

The above-mentioned consumptive takings and recharge reduction areas are classified as Significant Threats regardless of their location within the WHPA-Q. Municipal permitted water takings are classified as Significant Threats as increases in municipal pumping from a well may result in the water level in that same well to decline below its safe threshold.

After the Significant Threats were identified, the RMMEP and Threats Management Strategy were completed to recommend an overall plan to mitigate the threats and reduce the Risk Level (Matrix 2018).

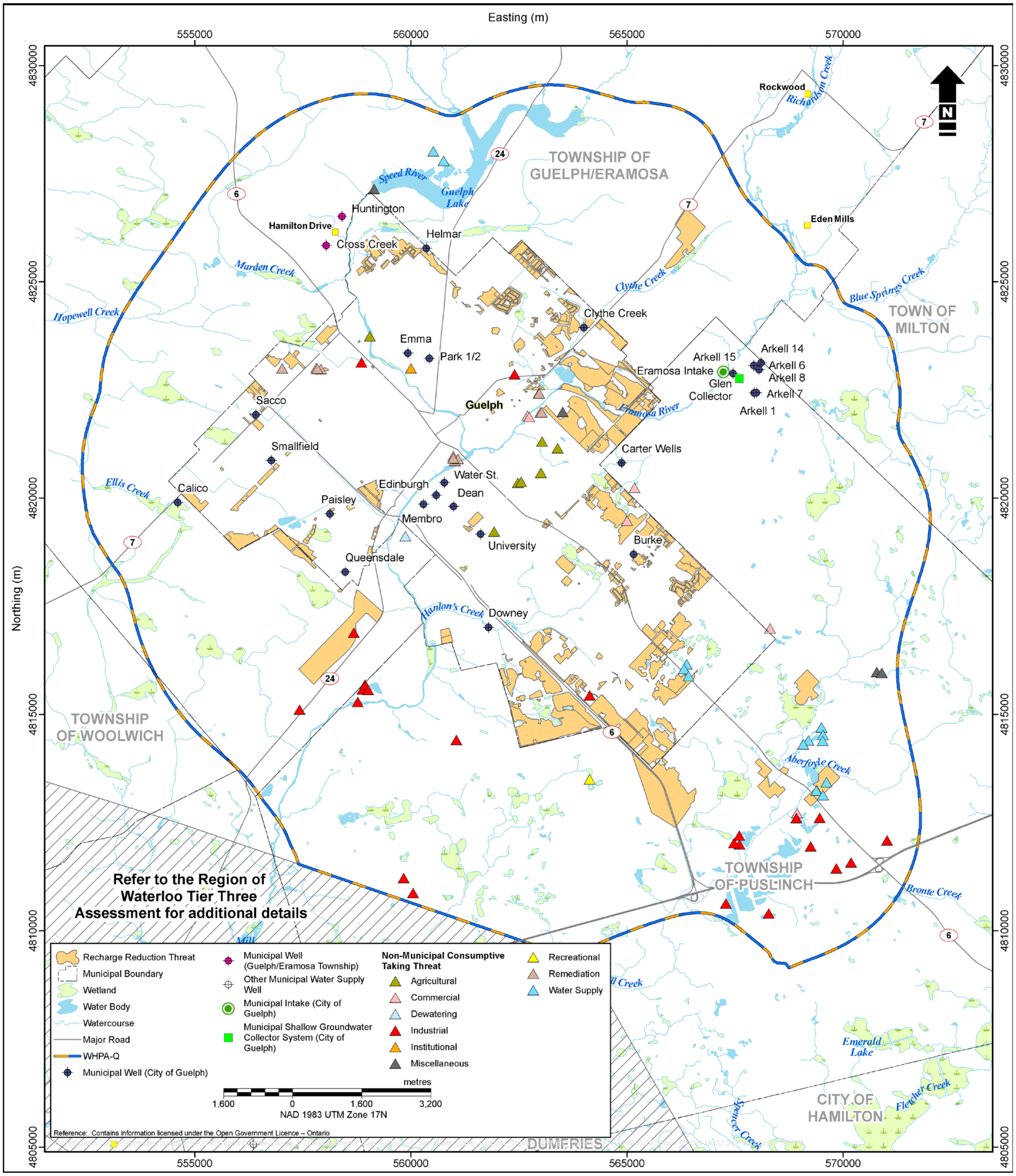

FIGURE 4 WHPA-Q Significant Water Quantity Threats (Matrix 2017)

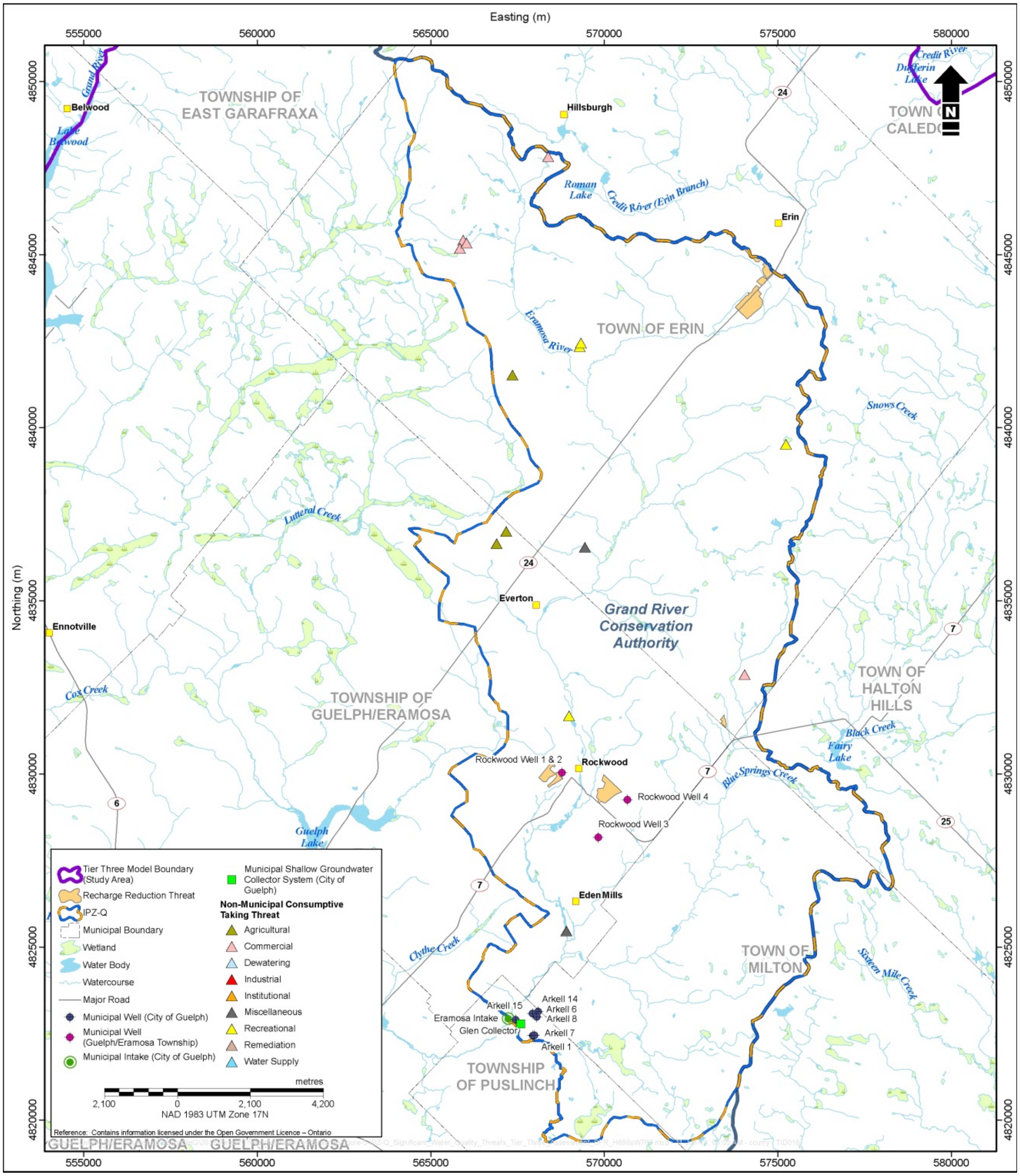

FIGURE 5 IPZ-Q Significant Water Quantity Threats (Matrix 2017)

2 CLIMATE CHANGE ASSESSMENT

This section summarizes an assessment of the potential impact of climate change as a threat to the quantity of municipal water supplies in GGET. The following subsections discuss future climate, hydrologic, and groundwater models, alternative climate change hydrology scenarios, and the predicted impact of those alternative scenarios on the GGET municipal water supplies (i.e., wells, intake, and Glen Collector).

2.1 Future Climate

The first technical phase of this project included the preparation of future local climate datasets. This phase leveraged existing information to achieve the overall outcome of constructing and analyzing an ensemble of future climate projections for temperature and precipitation variables. The analysis completed in this phase guided the development of scenarios for use in hydrologic modelling.

This phase included the following tasks:

- compiling an ensemble of future climates considering available Global Climate Models (GCMs) and Regional Climate Models (RCMs)
- completing a process, known as downscaling, to prepare local climate datasets from the GCMs and RCMs

The climate change methodology developed in the Guide for the Assessment of Hydrologic Effects of Climate Change in Ontario (EBNFLO and AquaResource 2010) was applied for this study. A selection of climate data from ten GCMs was used to develop climate change scenarios using the Grand River Conservation Authority's (GRCA) watershed hydrology model (GAWSER) and the GGET Tier Three groundwater flow model (FEFLOW). One RCM was used to develop a climate change hydrology scenario using a simple water balance model for the watershed.

Risk Sciences International (RSI; RSI 2016 and RSI 2018) worked under subcontract to Matrix to help compile future climate datasets for use in this study. RSI's report summarizing the selection of representative GCMs (RSI 2016) is provided in Appendix A. RSI's report summarizing the selection of a representative RCM (RSI 2018) is provided in Appendix B. RSI supported a climate change assessment for the Grand River Mill Creek Subwatershed (Matrix 2016) by compiling GCM results. These datasets were assumed valid for this study since they remain the most current GCM modelling results and are also relevant for the geographical area assessed by the GGET Tier Three model. RSI also compiled an RCM dataset for use directly in this study (RSI 2018).

2.1.1 Global Climate Models

The primary tools used to estimate future climate are GCMs. GCMs are complex, physically-based, three dimensional models that represent the earth's atmosphere, oceans, and land surfaces and simulate, over several decades, the interactions of processes that determine the climate for an area. These tools have evolved since the 1970s to their present level of sophistication. Numerous modelling centres around the world have developed GCMs that are used for long-term simulations (i.e., 250 year) to characterize the evolution of temperature, precipitation, solar radiation, winds, and other parameters well into the future. GCMs produce global scale output at a relatively course grid point spacing of 250 to 400 km. Simulations are designed to characterize future climate on an annual, seasonal, and monthly basis.

The Intergovernmental Panel on Climate Change (IPCC) is the most robust source of climate change science guidance, since it consists of thousands of contributing scientists. The IPCC has released its fifth Assessment Report (AR5; IPC 2013) which compiles the results of 40 different international climate change models. A new initiative in the IPCC AR5 is the introduction of Representative Concentration Pathways (RCPs). RCPs represent a range of possible projection outcomes which depend upon different degrees of atmospheric warming. The lowest RCP (RCP 2.6) represents an increase of 2.6 watts per square metre (W/m^2) to the system, while the highest RCP (RCP 8.5) represents an increase of 8.5 W/m^2 of energy. This range encompasses the best estimate of what is possible under a small perturbation situation (RCP 2.6) and under a large increase in warming (RCP 8.5). It is unknown which of the RCPs will apply in the future. However, it is important to note that historically, the greenhouse gas emissions have followed the highest (RCP 8.5) pathway.

2.1.2 Local Climate Datasets

While there are many GCMs available to describe future climates, the GCMs do not produce datasets that have the spatial or temporal refinement needed to support physically-based hydrologic modelling. There are several approaches to climate change modelling to produce locally relevant datasets. These approaches include dynamical downscaling, statistical downscaling, and the 'change field' approach.

Dynamical downscaling is a computationally intensive approach that involves running high resolution climate models on a regional subdomain (RCM). This allows for more complex datasets (i.e., topography) and detailed descriptions of physical processes to be incorporated in order to reproduce local climates. An RCM is a model nested into a portion of a GCM. The boundary conditions for an RCM are determined from GCM output for an isolated geographical area. These boundary conditions are then used by the RCM for computation of climate scenarios at higher resolution over the specified isolated area. RCMs are applicable to the current study due to the scale of the data requirements for the hydrologic analysis. Downscaling climate data is the general name of the procedure to generate locally relevant climate data from the results of a GCM or RCM.

The statistical downscaling approach involves the development of empirical relationships between local climate variables and large-scale predictors. Future atmospheric variables projected by GCMs can then be used to predict future local climate variables. Statistical downscaling is easy to implement but requires historical climate observations and relies on assumption that currently observed relationships will carry into the future (Trzaska and Schnarr 2014).

Another established methodology for estimating future local climates uses the GCM simulations to estimate annual, seasonal, or monthly changes for each climate variable for a future time period relative to a baseline climate period. These relative changes, termed 'change fields', are used to adjust observed climate station data time series to reflect future conditions. This approach results in an altered input climate time series that reflects the average relative change in each parameter and, through the use of local observations, the local climate. The change field method is a simple approach to develop future local climates that reflect large scale average features and allows the use of multiple GCM and greenhouse gas emission scenarios. The change field approach is used for this climate change assessment for the reasons described above and it can be applied consistently with the surface water and groundwater models developed for the GGET Tier Three Assessment.

The process of identifying an ensemble of future climates in Ontario is summarized in EBNFLO and AquaResource (2010). This guide provides an extensive review of future climate scenarios being used in hydrologic models, and provides step-by-step guidance and accompanying datasets for developing an ensemble of future time series for use in climate impact modelling (see http://waterbudget.ca maintained by the Ontario Ministry of Natural Resources and Forestry for the datasets).

RSI provided the climatology and climate change analyses for this study using quality controlled and peer reviewed climate change model outputs from the RSI climate analytical system. This involved using climate change model results from the 40 GCMs in AR5 (IPCC 2013). The most recent climate normal period was selected for the baseline period (1981-2010) and the 2050s period (2041-2070) was selected for future scenarios. The greatest greenhouse gas concentration trajectory, RCP 8.5, was chosen since it best represents the current emissions trajectory.

2.1.2.1 Selection of GCM Models

Uncertainties in future climate predictions include unknown future emissions of greenhouse gases and aerosols, the conversion of emissions to atmospheric concentrations and to radiative forcing of the climate, modelling the response of the climate system to forcing, and methods for regionalizing GCM results (IPCC 2013). Uncertainties will remain inherent in predicting future climate change, even though some uncertainties will likely be narrowed in time due to climate change modelling and computational improvements.

The IPCC recommends that water resource practitioners utilize as many future climate simulations as possible when conducting a climate change impact assessment. However, in most assessments it is impractical to conduct an evaluation with the full set of over 60 future climate simulations. The ensemble approach to climate model analysis is widely recognized as being a reliable and efficient way of studying local trends associated with climate change while also characterizing uncertainties associated with projecting future climate, particularly for use in hydrologic modelling. The ensemble approach involves using a "collection of model simulations characterizing a climate prediction or projection" (IPCC 2013). There are many possible ways of constructing an ensemble of future climates that captures the full range of uncertainty associated with the selection of the emission scenario, GCM, and downscaling method. Each of these elements within an ensemble (i.e., emission scenario, GCM, and downscaling) can greatly influence the final outcome of an individual time series, which may also vary by location and time horizon of interest.

RSI estimated the monthly and annual temperature and precipitation for 57 GCM scenarios in the Guelph area. Figure 6 illustrates a scatter plot of simulated annual mean change in temperature and precipitation for the 2050s (2041-2070) for these 57 scenarios. This figure displays the level of disparity among GCM models as mean annual temperatures range from +1.7 to +4.6 °C, while annual precipitation changes range from -4 to +20%.

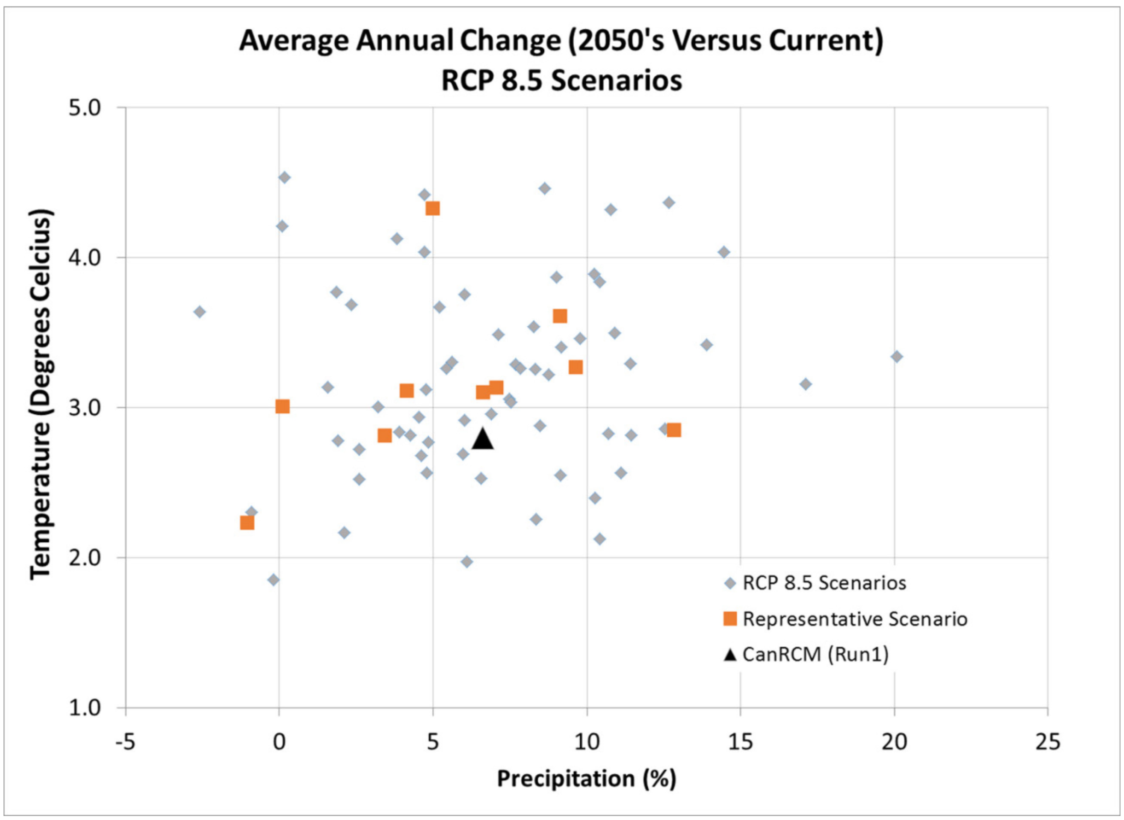

FIGURE 6 Scatter Plot of Annual Change Fields for Climate Models

RSI (2016) provides a detailed review of the existing climates sets considered for this assessment. A subset of 10 GCM climate datasets was selected through assessment of the change in mean annual temperature and precipitation between baseline and future periods. Each GCM RCP8.5 model was ranked and the 5th, 25th, 50th, 75th, and 95th percentile projections for each of these parameters were selected. This resulted in ten climate change scenarios which are summarized in Table 1. All GCM scenarios predict an increase in temperature and nine of ten scenarios predict and increase in precipitation on an annual average basis.

TABLE 1 Selected Ensemble of GCM Models

Scenario	Percentile	Parameter	GCM	Annual Temperature Change (deg. C)	Annual Precipitation Change (%)
CLM1	5th	Temperature	FIO-ESM(Run 1)	2.23	-1.05
CLM2	25th	Temperature	CCSM4(Run 1)	2.82	3.43
CLM3	50th	Temperature	CSIRO-Mk3-6-0(Run 10)	3.14	7.05
CLM4	75th	Temperature	CESM1-CAM5(Run 2)	3.61	9.12
CLM5	95th	Temperature	MIROC-ESM(Run 1)	4.33	4.96
CLM6	5th	Precipitation	IPSL-CM5A-MR(Run 1)	3.01	0.08
CLM7	25th	Precipitation	CNRM-CM5(Run 1)	3.11	4.12
CLM8	50th	Precipitation	NorESM1-M(Run 1)	3.10	6.62
CLM9	75th	Precipitation	ACCESS1-3(Run 1)	3.27	9.62
CLM10	95th	Precipitation	CMCC-CESM(Run 1)	2.85	12.82

2.1.2.2 Canadian Regional Climate Model

The Canadian Regional Climate Model was originally developed at the University of Quebec in Montreal. The regional model is currently in its fourth generation (CanRCM4) and is maintained by the Canadian Centre for Climate Modelling and Analysis. The CanRCM4 uses a 25 m grid and can be applied to any location globally. Various emissions scenarios are available for simulations within the CanRCM4 model. The model was selected for this study in part due to its direct applicability and development within Canada.

For the remainder of the report we will refer to the CanRCM4 model as simply the RCM. RSI extracted daily temperature and precipitation data from the RCM for the 1981-2100 period for the Guelph area (Waterloo Wellington Airport). The 1981-2010 period is considered as baseline and also used to validate the RCM. Validation of the RCM output is required to compare the model's output from a historical period to actual measured climate, and use those results to interpret future model predictions.

The GGET Tier Three Assessment has relied on local climate data measured at the Guelph Turfgrass Institute (GTI). The Waterloo Wellington Airport and GTI are within the same grid cell. The RCM's mean annual temperature for the 1981-2005 period is 9.5°C as compared to the mean annual temperature of 6.9°C measured at the GTI. This is approximately a 2.6 degree warm 'bias', which is typical for the CanRCM4 in Southern Ontario.

For precipitation, the RCM, like many climate models, produces precipitation on almost every day, but at very small amounts (e.g., less than 0.5 mm or 1.0 mm). For the purposes of hydrologic modelling, these low daily amounts are generally set to zero. In this case, total precipitation from the RCM was summed after resetting any total daily amounts less than 0.5 mm to zero. For the period of 1981-2005 the mean annual average precipitation in the grid cell was calculated as 875 mm. This result is very close to the average annual precipitation recorded at GTI.

The mean monthly and annual average precipitation and temperature for the RCM baseline and future scenarios are summarized in Table 2.

TABLE 2 Regional Climate Model Baseline vs Future - Precipitation and Temperature

Month	Precipitation (mm)			Temperature (°C)		
	1981-2010	2041-2060	2081-2100	1981-2010	2041-2060	2081-2100
1	59	56	77	-7.5	-4.7	-0.7
2	54	74	84	-6.6	-2.4	0.3
3	83	89	89	-1.4	1.7	3.6
4	78	92	98	6.0	8.4	11.0
5	85	91	139	12.2	15.6	18.5
6	100	108	66	17.9	21.4	24.5
7	82	87	94	20.1	23.6	26.6
8	75	73	76	20.9	23.7	27.6
9	55	55	36	15.9	19.8	23.8
10	52	50	60	8.2	11.4	15.3
11	72	92	81	1.4	4.0	6.6
12	79	73	101	-3.3	-1.4	0.5
Annual	**875**	**941**	**1,001**	**7.1**	**10.2**	**13.2**

As summarized in the above table, the RCM predicts an increase of temperature of 7.5% and 14.5% for the 2041-2060 and 2081-2100 periods, respectively. The RCM also projects an increase in average annual temperature of 3.1°C and 6.1°C for the same future time periods. The projected average increases in temperature and precipitation for the 2041-2060 period are in the middle range of GCM projections, as illustrated on Figure 6.

The following figure summarizes this monthly, as average temperature over the time period for January, April, July, and October. As illustrated on this figure, the rate of change for the increase in temperature is linear across all months and is not significantly different for any specific month.

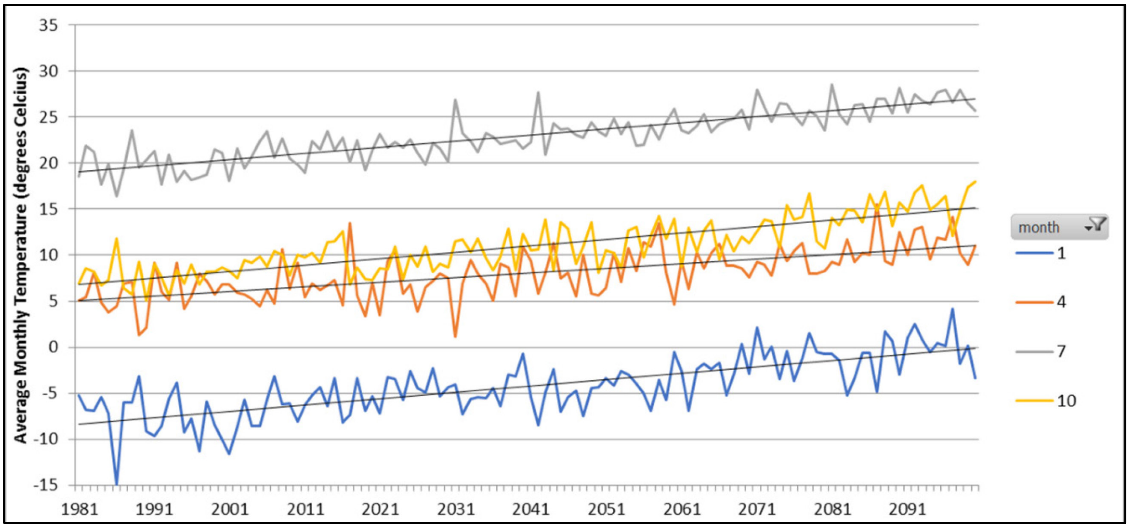

FIGURE 7 Monthly Temperature, 1980-2100 (CanRCM4 Run1)

The following figure illustrates projected average monthly temperature for the periods 1991-2010, 2021-2040, 2041-2060, and 2081. As shown by this figure, the RCM predicts the increase of temperature to be generally consistent across all months of the year; however, the total increase in temperature is predicted to be greatest during the January to March and June to September periods.

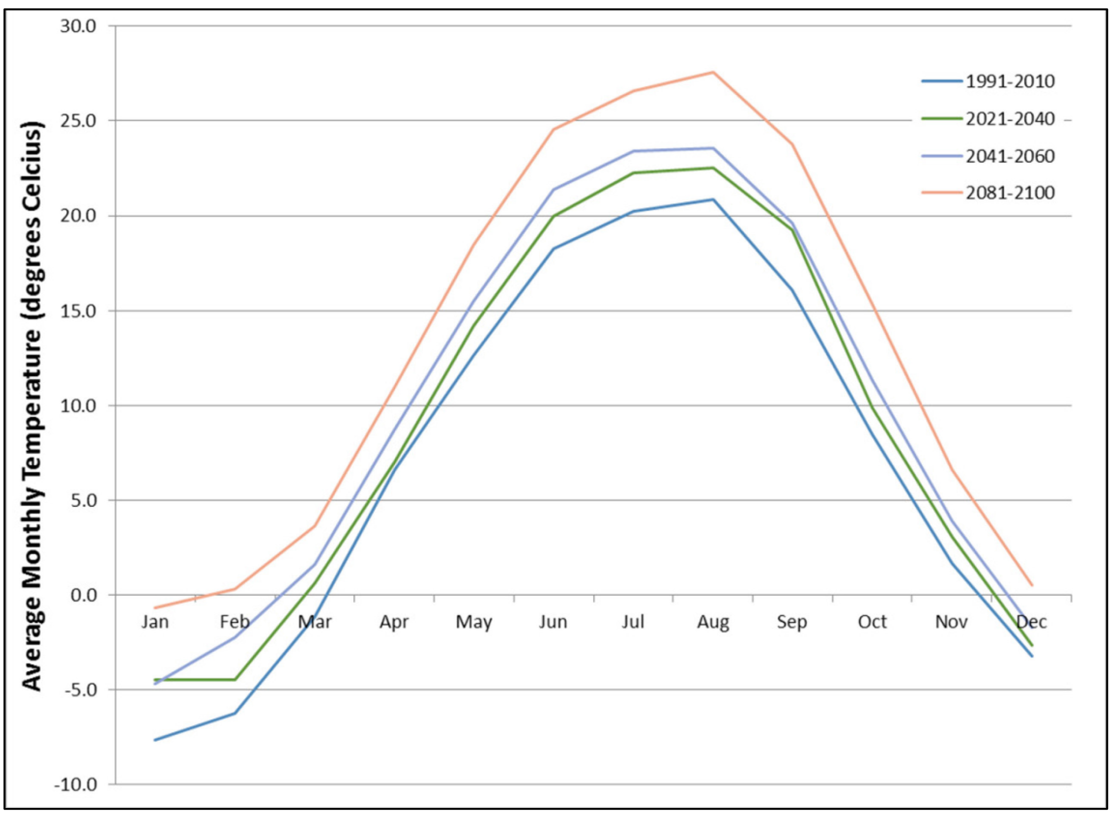

FIGURE 8 Average Monthly Temperature (CanRCM4 Run1)

The following figure illustrates the RCM's projected annual precipitation for the 1981-2100 period.

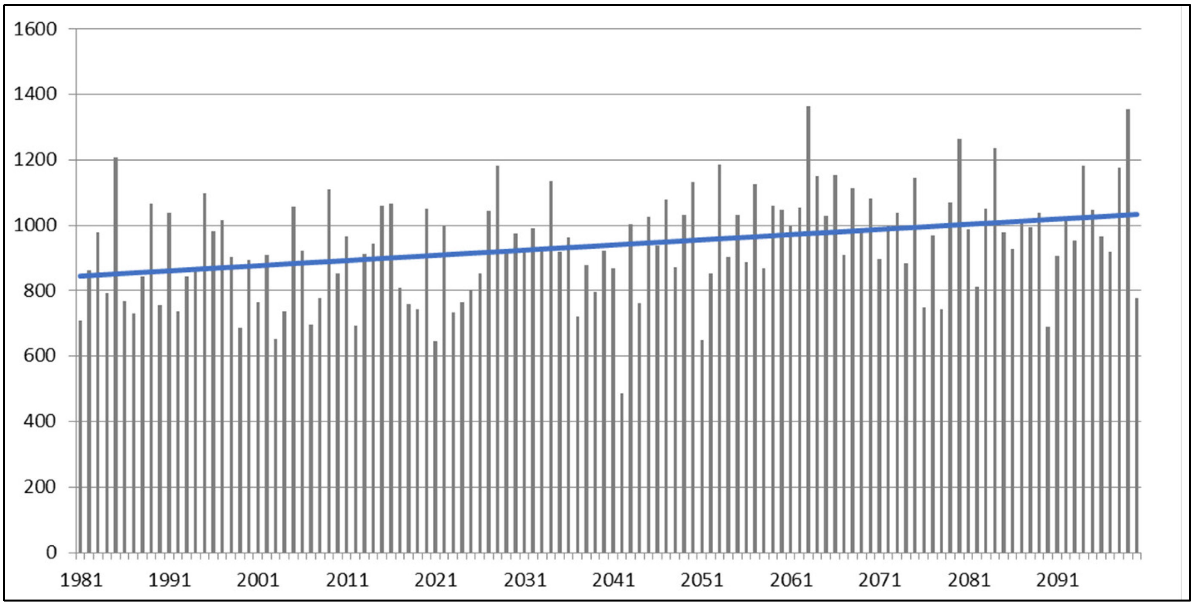

FIGURE 9 Annual Precipitation (CanRCM Run1)

2.2 Description of Hydrologic Models

After assembling future climate datasets, the application of hydrologic models is the next step in a climate change assessment. The hydrologic models have the capability to estimate change in the water budget parameters (e.g., runoff, evapotranspiration, and groundwater recharge) under future climate scenarios. This section describes two hydrologic models used to predict hydrologic water budget parameters across the watershed contributing to the GGET drinking water supplies. These two hydrologic models include a simple watershed-wide water balance model and the existing Grand River hydrology streamflow generation model, GAWSER (Guelph All-Weather Sequential Events Runoff).

2.2.1 Water Balance Model

A spreadsheet-based water balance model was developed to estimate daily water budget parameters for daily temperature and precipitation projections provided by the RCM. During a changing climate scenario, potential evapotranspiration (PET) increases over time with increasing temperature. GAWSER cannot accommodate increases in PET over time and therefore could not be used to simulate hydrologic response to the RCM climate.

The daily water balance model is a general predictor of hydrological conditions over the watershed, and is not intended to predict locally precise water budget values. However, the water balance model serves as useful tool to visualize how the important hydrological water balance parameters including runoff, evapotranspiration, and groundwater recharge are likely to change in response to the RCM's forcing climate variables.

2.2.1.1 *Model Development*

Figure 10 illustrates the logic associated with hydrologic processes and water storage reservoirs represented in the daily water balance model. These processes and reservoirs are typical of general rural hydrologic models and can be parameterized based on the general characterization of the landscape, soils, and shallow groundwater conditions.

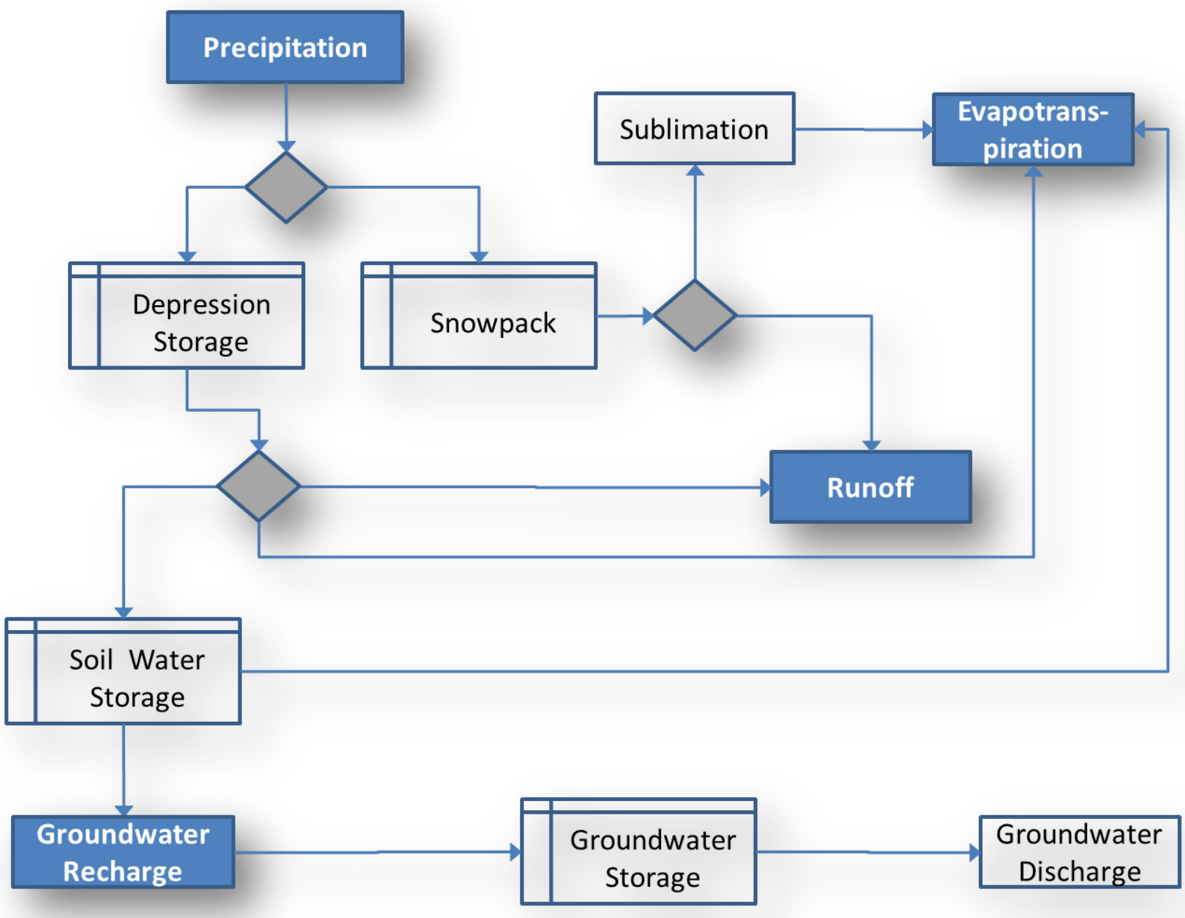

FIGURE 10 Water Balance Model - Hydrologic Processes and Water Storage

The hydrologic processes illustrated in the above figure are all expressed as rate of mm/day and are summarized as follows:

- **Daily Precipitation.** Daily precipitation is provided as input into the model, either as actual daily observation records, or as daily output from the RCM. Where average daily temperature is less than zero, daily precipitation is assumed to be snow.
- **Sublimation.** Sublimation is the process of solid snow changing phases into gas. In the water balance model, the rate of sublimation is assumed as constant and modified during model calibration.

- **Evapotranspiration.** Evapotranspiration represents the total amount of water that enters the atmosphere. It can originate as sublimation, as evaporation from depression storage, or as evaporation from soil water storage. The maximum rate of evapotranspiration for a given day is limited by the PET as calculated using the Thornthwaite Model. The actual rate of evapotranspiration for a given day is limited by the water in depression storage and soil water storage.
- **Direct Runoff.** Direct runoff is the process of water travelling overland, or through shallow preferential pathways, directly into a watercourse. Direct runoff occurs when rainfall exceeds the amount of depression storage or when snowmelt occurs.
- **Snowmelt.** Snowmelt is the process of water melting from the snowpack, transforming into liquid water and direct runoff. In this model the snowmelt rate is calculated as the average temperature (above freezing) multiplied by a constant.
- **Infiltration.** Infiltration is the process of water moving from depression storage into soil water storage. In the water balance model, infiltration is considered as a single average rate of water movement that will occur providing there is water held in depression storage. In this model, infiltration is not allowed if the average 5-day temperature is less than zero.
- **Groundwater Recharge.** Recharge is the process of water moving from soil water storage into groundwater storage. In the water balance model, groundwater recharge is calculated by multiplying the amount of water held in soil water storage by a constant. This representation is referred to as a linear reservoir.
- **Groundwater Discharge**. Groundwater discharge refers to water that migrates from groundwater storage into surface water. In this model, the rate of groundwater discharge is calculated by multiplying the total amount of groundwater storage by a constant. This representation is referred to as a linear reservoir.

Water storage reservoirs are described in the model to store water through various steps of the hydrologic cycle. The reservoirs represented in the simple water balance model are summarized as follows:

- **Snowpack.** Snowpack is the term referring to the average amount of frozen snow on the land surface.
- **Depression Storage.** Depression storage is the maximum amount of water, in mm, that is stored on the land surface before it is able to move through the direct runoff or infiltration process. Water can be stored in various features including ponding or vegetation.
- **Soil Water Storage**. Soil water storage refers to water that is stored in the unsaturated zone above the water table.
- **Groundwater Storage.** Groundwater storage refers to water that migrates from soil water storage through groundwater recharge, into groundwater aquifers. Some of this water ultimately discharges into surface water features.

2.2.1.2 Model Calibration

Before applying the model to evaluate a climate change scenario it is necessary to apply the model using actual measured precipitation and compare simulated streamflow against observed streamflow. This step in the modelling process is called model calibration. The result of model calibration is identifying a series of model parameters that ideally can be used to allow the model to predict hydrologic processes over the same area using different climate estimates.

Model calibration was achieved using long-term streamflow monitoring at the GRCA's streamflow gauge on Eramosa River at Watson Road. Historical temperature and precipitation monitoring data is available at the GTI for the period of 1950-2005.

The model calibration was completed over the period of 1950-2005. The initially estimated model parameters were iteratively adjusted until average annual estimated streamflow was similar to observed conditions, and simulated hydrologic response was similar to observed conditions.

Figure 11 illustrates simulated and measured daily streamflow during the period of 2002-2003. As illustrated on the figure, the model's prediction of baseflow is generally representative of wet and dry conditions. Similarly, the model's response to individual rainfall events is similar to observed conditions. The model is a simplification of actual watershed conditions and, as a result, there are many small-scale processes and events that are not reflected in the model results. Many short-term runoff events happen over a time-scale less than a day, and as a result, those short-term events are not seen in the water balance model results.

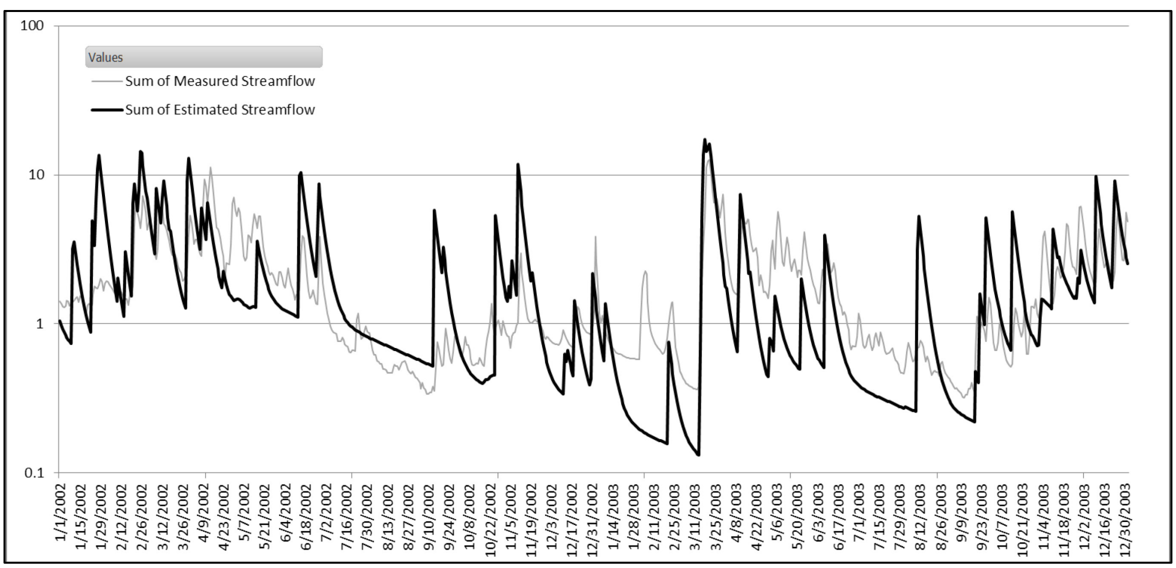

FIGURE 11 Simulated Versus Observed Streamflow at Eramosa Gauge

Table 3 summarizes the average annual estimates of key water budget parameters for the 1980-2005 period, as estimated by the water balance model. These water budget estimates would represent average annual conditions over the Eramosa River Watershed upstream of the Eramosa River at Watson

Road streamflow gauge. The water budget parameter estimates are consistent with those made using the GAWSER model.

TABLE 3 Average Annual Water Budget Over Eramosa River Watershed (1980-2005), Water Balance Model

Water Budget Parameter	Average Annual Total (mm/year)	Proportion of Precipitation
Total Precipitation	867	
Direct Runoff	254	29%
Evapotranspiration	504	58%
Groundwater Recharge	111	13%

2.2.2 Grand River Hydrology Model

As part of the GGET Tier Three Assessment, surface water and groundwater modelling tools were developed to help assess the sustainability of the municipal water sources. The models were developed based on a detailed characterization of the groundwater and surface water systems, and they were refined to a level supported by available data. The models were calibrated to represent typical operating conditions under average (steady-state) and variable (transient) pumping conditions. The continuous streamflow-generation model was developed using GAWSER (Schroeter & Associates 2004) and will be discussed in the following subsections. The groundwater flow model was developed using FEFLOW (Diersch 2006) based on the best geological and hydrogeological data available for the Study Area and will be discussed in Section 2.4. These models were applied for the current climate change assessment.

2.2.2.1 Model Description

The GAWSER streamflow generation model is a physically based, deterministic hydrologic model used to predict the total streamflow resulting from inputs of rainfall and/or snowmelt. It can operate in both continuous and event-based modes. It can be used to model recharge ponds and can predict pollutant accumulation, wash off, and transport. Climate input data required for continuous modelling includes daily maximum and minimum temperatures, daily total precipitation, and hourly rainfall.

The GRCA developed and calibrated a continuous GAWSER model to simulate the hydrology of the Grand River Watershed. The hydrologic model was originally constructed for flood forecasting purposes in the late 1980s, and the model has continually improved and evolved since that time as new information and updates in conceptualization have evolved. The event-based model was converted to a continuous model in the late 1990s when a substantial calibration and verification exercise was carried out.

More recently, the GAWSER model was applied to estimate groundwater recharge rates across the Grand River Watershed. The GRCA revisited the model as part of the Grand River Tier Two Water Budget (AquaResource 2009a) and Subwatershed Stress Assessment (AquaResource 2009b). Subsequently the GAWSER model was refined within the Tier Three Assessment Study Area to better represent current land use and groundwater recharge rates and to improve the simulated streamflow in the Eramosa River supplying the City of Guelph's surface water intake. Within the Study Area, the GAWSER model refinements focused on improving the calibration of the Mill Creek Subwatershed, Upper Speed River Watershed, Eramosa River Watershed, and Blue Springs Creek Subwatershed. The land areas associated with these drainage areas represent a large proportion of the Study Area and the key groundwater recharge areas associated with the municipal drinking water supplies.

2.2.2.2 Model Updates

Several minor modifications were made to the calibrated GAWSER model to make it suitable for assessing the 2050s future climate scenarios. Potential evapotranspiration was calculated for the 2050s period based on the estimated temperature for each of the GCMs. GAWSER also includes monthly infiltration factors which have been calibrated to 1950-2005 conditions. These factors account for the influence of frozen ground in limiting infiltration during the winter months. These monthly factors were adjusted to be consistent with predicted monthly temperature changes during the 2050s.

2.3 Climate Change Hydrology Scenarios

This section describes the application of the simple water balance model and the GAWSER model to estimate hydrologic parameters under the RCM and GCM ensemble scenarios.

2.3.1 Regional Climate Model and Water Balance Model

The spreadsheet-based simple water budget model was applied to estimate the daily change in key hydrologic parameters over the RCM's 1980-2100 climate period.

2.3.1.1 Projected Changes in Water Budget

The water budget model predicts surface water runoff, total evapotranspiration, and groundwater recharge on a daily basis over the 1980-2100 future climate prediction. The following table summarizes average annual estimate of these parameters for the 1981-2010 (baseline), 2041-2060, and 2081-2100 periods.

TABLE 4 Projected Changes in Annual Water Budget (mm/year; RCM Water Balance Model)

Water Budget Component	1981-2010	2041-2060	2081-2100
Precipitation	877	941	1,001
Runoff	229	242	257
Evapotranspiration	496	491	480
Groundwater Recharge	151	208	263

As summarized in the above table, the RCM predicts the average annual precipitation to increase to 941 mm/year and 1,001 mm/year for the 2041-2060 and 2081-2100 periods, respectively. Average annual runoff increases from 229 mm/year to 242 mm/year and 257 mm/year for these two periods. Evapotranspiration is predicted to decrease slightly from 496 mm/year to 491 mm/year and 480 mm/year for these two periods. Groundwater recharge rates are predicted to increase from 151 mm/year to 208 mm/year and 263 mm/year for the two future time periods.

The increase in surface water runoff is intuitively consistent with having an increase in precipitation for the future climate period. However, having a decrease in total annual evapotranspiration and an increase in average annual groundwater recharge is less intuitive. The following figures illustrate the temporal changes in water balance parameters over the future climate period and help explain the predicted changes in water balance parameters.

Figure 12 illustrates the predicted annual trend in the four main water balance parameters for the RCM. As described previously, average annual precipitation as predicted by the RCM increases from 877 mm/year to more than 1,000 mm/year. While the trend for evapotranspiration and surface water runoff remains relatively flat, the surplus precipitation is mainly ending up as groundwater recharge.

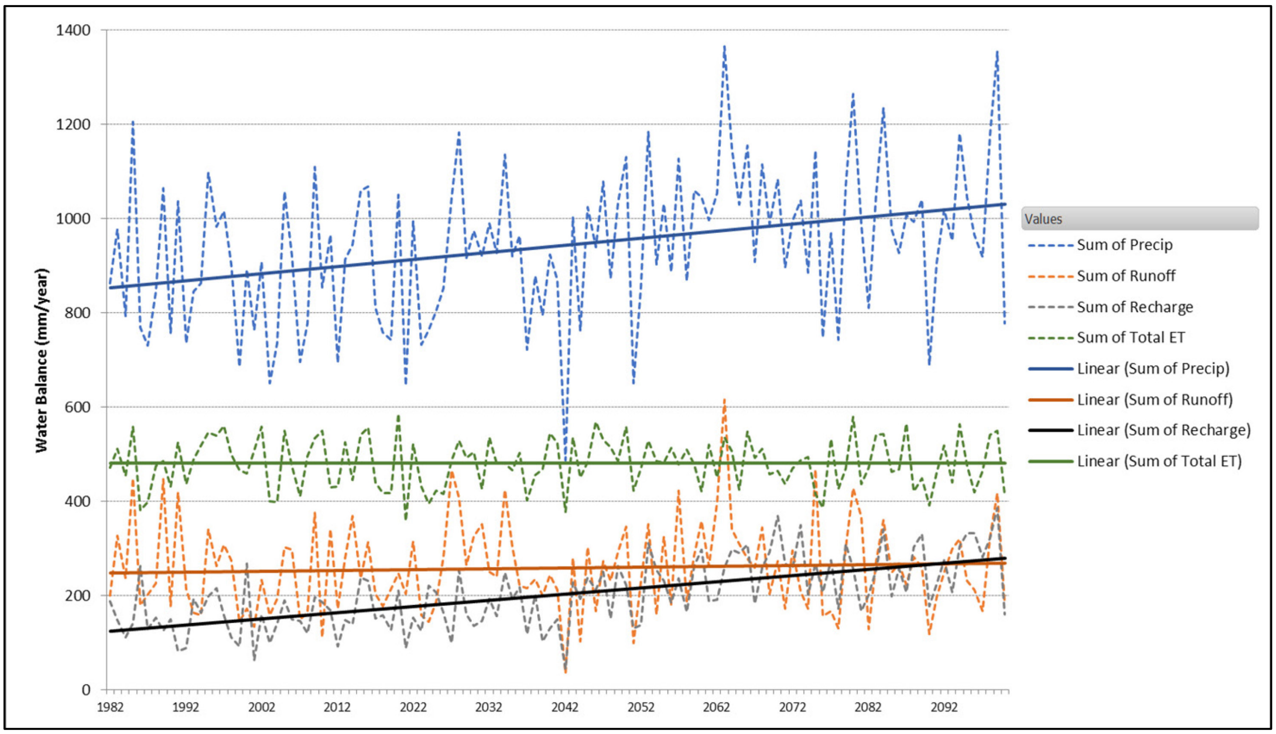

FIGURE 12 Projected Average Annual Water Budget (RCM Water Balance Model)

Figure 13 illustrates the trend in average winter snowpack and average winter temperature as predicted by the water balance model. As expected, average winter temperature increases over time. Around the 2040-2060 period, there are years when the average winter temperature is close to freezing. As a result, the average snowpack in those years is minimal.

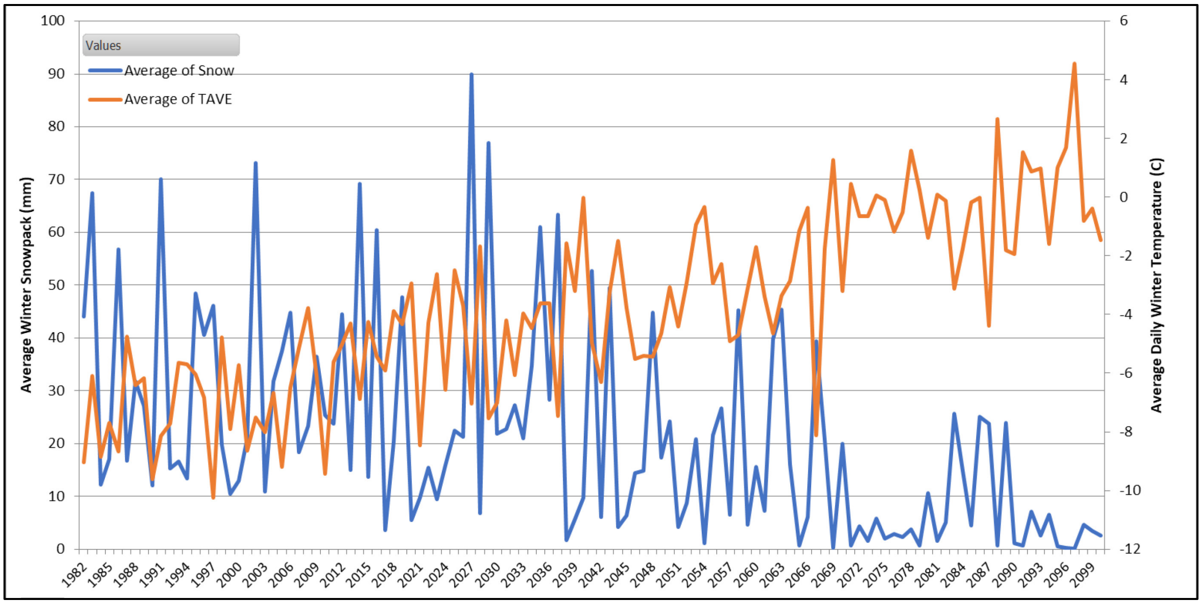

FIGURE 13 Average Winter Snowpack and Daily Temperature (RCM Water Balance Model)

Figure 14 illustrates the average winter (Dec, Jan, Feb) water budget parameters over the 1980-2100 period. This figure illustrates that while water budget parameters can fluctuate significantly from year to year, there are trends in these values over time. The most significant trend appears with groundwater recharge, which has an average value of approximately 30 mm/year early on but increases to an average value of approximately 150 mm/year at 2100. The average value is approximately 75 mm/year in the period around 2050. The increase in predicted winter groundwater recharge rates are a result of increased winter precipitation, thawed ground conditions, and low winter evapotranspiration. Increased winter groundwater recharge is the primary driver in the increase in total annual groundwater recharge.

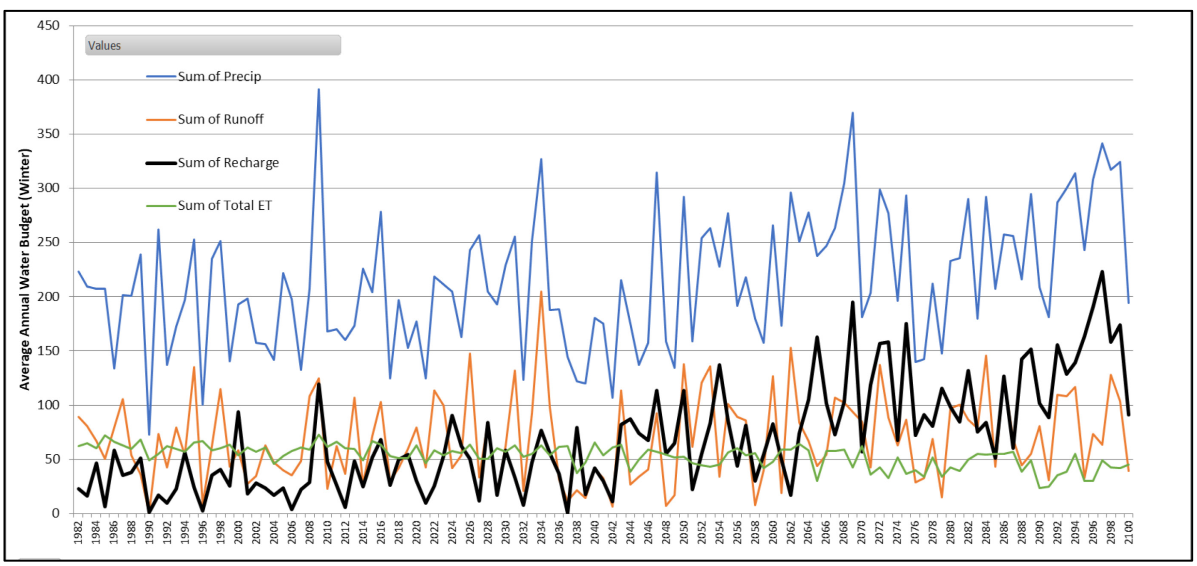

FIGURE 14 Projected Average Winter (Dec, Jan, Feb) Water Budget (RCM Water Balance Model)

The remaining trend observed with the water balance model is that of total annual evapotranspiration which remains relatively constant over the 1982-2100 period. PET is the maximum amount of water that may be subject to evapotranspiration and this amount increases in the future within increasing temperature. Actual evapotranspiration is limited, however, by the amount of water available in soil, plants, and water bodies. For the water balance model developed in this assessment, available soil water becomes limited during summer months and as a result, actual evapotranspiration does not increase in the future. A more rigorous water balance or hydrologic model may account for different soil conditions, water bodies, and wetlands, and may predict increasing evapotranspiration rates for future climate conditions.

2.3.2 Watershed Hydrology Model - GCM Change Fields

This section describes the application of the GAWSER model to simulate hydrologic parameters in response to the 2050s change fields calculated for ten GCMs. Although the model simulates a wide range of hydrologic parameters distributed over the watershed; this section focusses on the simulated results for streamflow and groundwater recharge.

2.3.2.1 Modelling Approach

Figure 15 is a scatter plot illustrating average annual temperature and precipitation change fields for all RCP 8.5 scenarios considered. The figure highlights in orange the ten representative scenarios selected using the percentile method described earlier in Section 2 to encompass the range in variability for all of the GCMs.

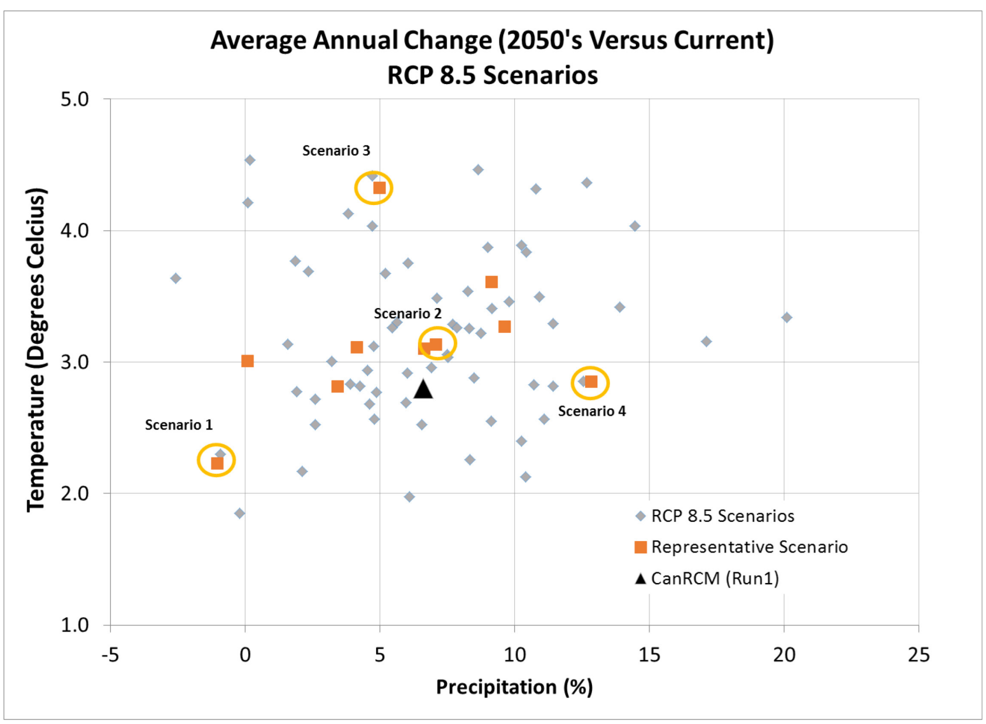

FIGURE 15 Scatter Plot of Future Climate Models Selected for Hydrologic Modelling

The groundwater modelling scenarios described in Section 2.4 are computationally demanding, and as a result four representative GCM datasets were selected (Figure 15) from the larger set of GCMs encompassing the range of variability of all the GCMs. The following table lists all GCMs used to drive the surface water and groundwater modelling scenarios.

TABLE 5 Selected Ensemble of GCM Models used for Surface Water and Groundwater Modelling

Climate Scenario	Global Climate Model	Temperature Change	Precipitation Change	Surface Water Modelling	Groundwater Modelling
CLM1	FIO-ESM(Run 1)	2.23	-1.05	✓	✓(Scenario 1)
CLM2	CCSM4(Run 1)	2.82	3.43	✓	
CLM3	CSIRO-Mk3-6-0(Run 10)	3.14	7.05	✓	✓(Scenario 2)
CLM4	CESM1-CAM5(Run 2)	3.61	9.12	✓	
CLM5	MIROC-ESM(Run1)	4.33	4.96	✓	✓(Scenario 3)
CLM6	IPSL-CM5A-MR(Run 1)	3.01	0.08	✓	
CLM7	CNRM-CM5(Run 1)	3.11	4.12	✓	
CLM8	NorESM1-M(Run 1)	3.10	6.62	✓	
CLM9	ACCESS1-3(Run 1)	3.27	9.62	✓	
CLM10	CMCC-CESM(Run 1)	2.85	12.82	✓	✓(Scenario 4)

Appendix C summarizes the 2050s monthly change fields for the ten selected GCMs. These monthly change fields represent the relative change for each of the GCMs in the 2050s as compared to baseline conditions. Ten future (2050s) climate datasets were created by modifying the 1950-2005 GTI climate dataset by these monthly change fields. The ten modified 1950-2005 climate datasets were then run in the GAWSER model resulting in ten different time series describing the variability of water budget parameters that might be expected in 2050.

2.3.2.2 Changes in Water Budget Parameters

Figure 16 illustrates the range in predicted mean monthly flow for the ten future representative 2050 scenarios as compared to baseline conditions. Recall that the 2050s scenarios are derived from average GCM projections for the 2041-2070 period. The range of predicted future streamflow in winter (December to April) is generally higher than baseline conditions. This increase in streamflow is a result of higher precipitation and less accumulation of snow. Mean predicted streamflow during the summer months is slightly lower than baseline and generally similar to baseline during spring and fall months.

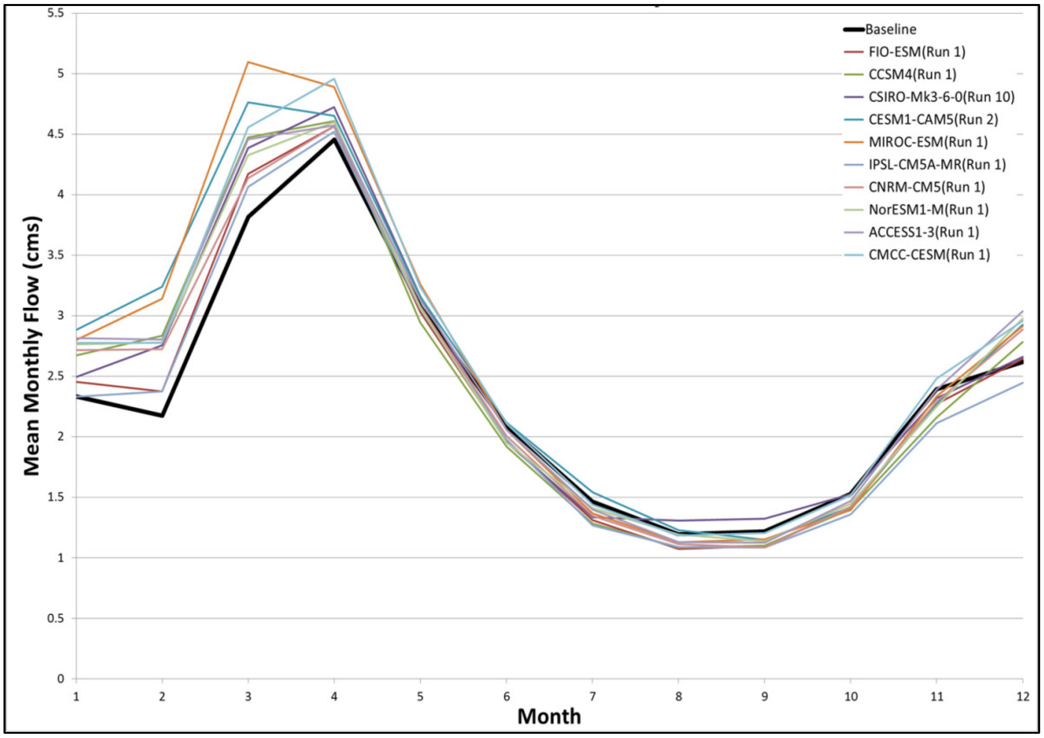

FIGURE 16 Mean Annual Flow in Eramosa River (2050s versus Baseline)

Figure 17 illustrates mean daily recharge in the 2050s for a silty sand soil for each month. The daily recharge predicted for the future climate scenarios is considerably higher than baseline conditions during the December to March period and this is a result of having less frozen soil and increased precipitation. Groundwater recharge during the summer months is generally less than baseline conditions and similar to baseline during spring and fall.

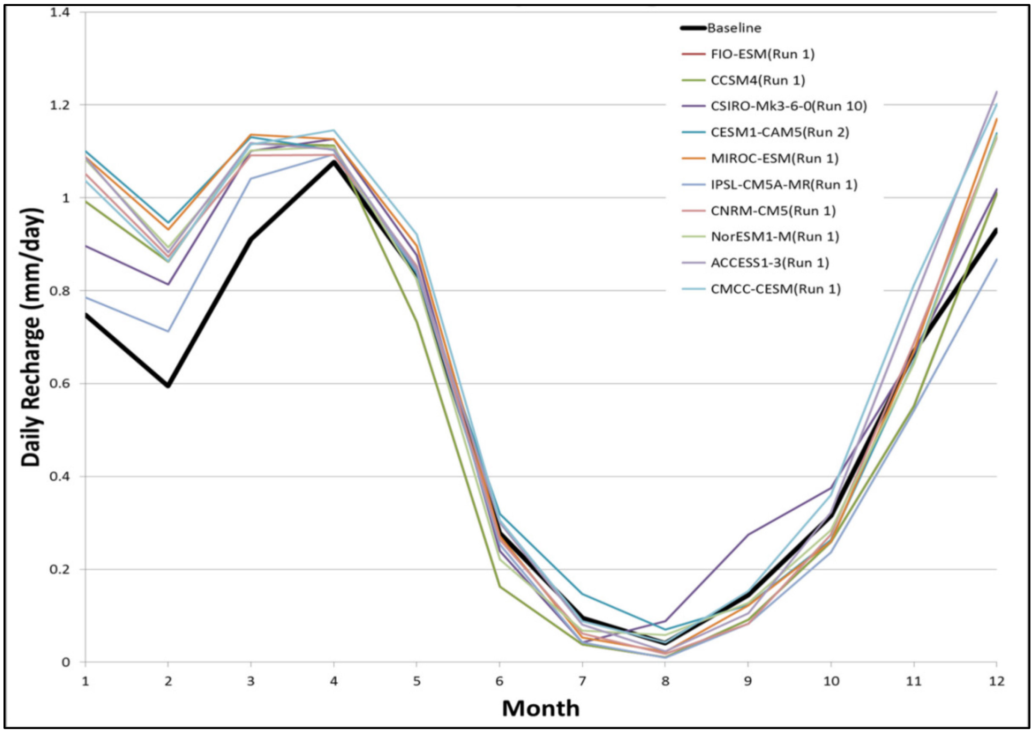

FIGURE 17 Estimated Mean Daily Recharge (2050s versus Baseline)

Figure 18 illustrates average daily recharge rates over the 1960-1969 drought period and adjusted for each of the 10 2050s GCM change field scenarios during the 1960-1969 period. This period has been referred to as the drought scenario in the GGET Tier Three Assessment as it is associated with the lowest average predicted groundwater recharge rates over the 10 year period. As shown on the figure, most groundwater recharge occurs during the spring of each year, and there is little to no groundwater recharge during many of the summer months.

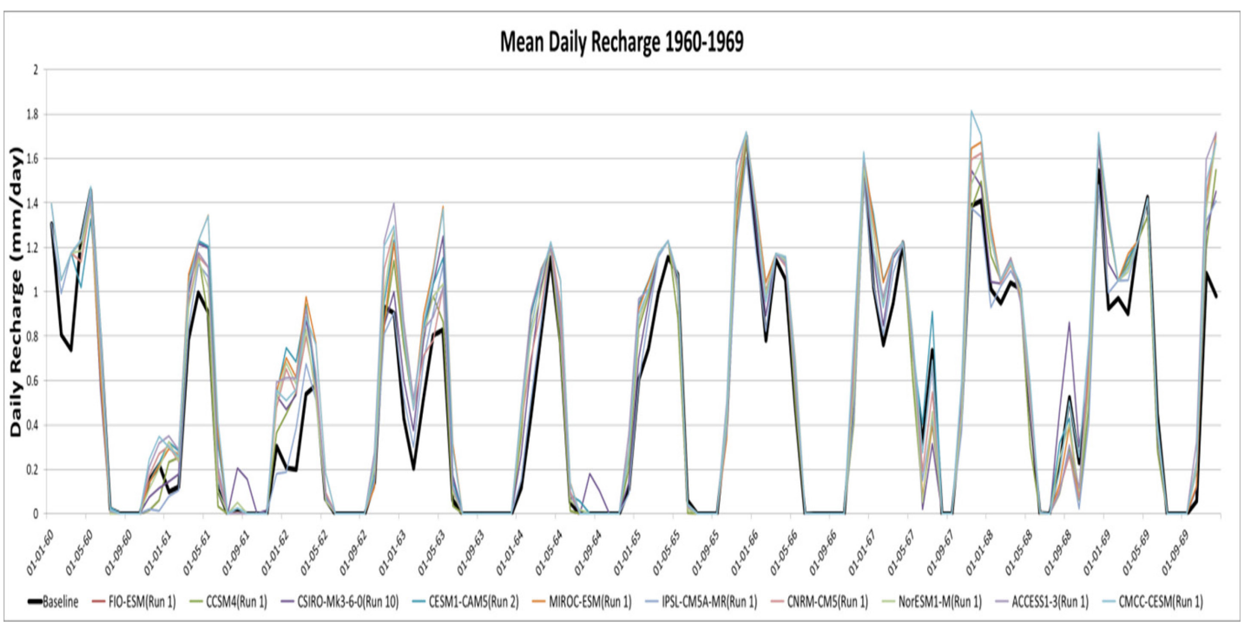

FIGURE 18 Estimated Recharge During Drought Scenario (10 GCMs; 2050s versus Baseline)

Predicted groundwater recharge rates under the conditions associated with the ten future climate scenarios are almost always higher than under baseline conditions. Higher groundwater recharge rates is a result of the change in winter or early spring conditions when higher temperatures result in less snowpack, shorter periods of frozen ground, and a greater ability for water to infiltrate.

2.4 Description of Groundwater Model

A FEFLOW groundwater flow model was previously developed for the GGET Tier Three Assessment to assess the potential impacts of increased municipal groundwater demands, land use change, and drought conditions on water uses. The model was based on a detailed conceptual model of the geologic, hydrogeologic, and hydrologic systems in the regional area, with particular focus on the areas surrounding the municipal well fields and intake. The development of the model built upon the approach used to create the Guelph-Puslinch groundwater flow model (Golder 2006).

The GGET Tier Three model was calibrated to long-term steady-state conditions and to transient conditions that included the simulation of a long-term pumping test (City of Guelph) and shorter-term tests (Rockwood and Aberfoyle). Transient model verification was also undertaken to confirm the performance of the model under transient conditions in the City of Guelph and in the Rockwood and Hamilton Drive areas. The steady-state groundwater flow model was calibrated to hydraulic head measurements from Ontario Ministry of the Environment, Conservation and Parks domestic water wells records, City of Guelph and Township of Guelph/Eramosa high-quality monitoring wells, and other high-quality wells that are part of other studies. The model was also calibrated to low streamflow targets estimated from spot baseflow observations and streamflow gauge data collected at locations throughout the Study Area.

Calibration of the groundwater flow model relied on estimates of groundwater recharge across the landscape represented by the model. Groundwater recharge estimates used in the calibration of the model include the following:

- The Grand River Watershed GAWSER streamflow generation model (described in Section 2.2.2)
- The Credit River Watershed HSP-F model (AquaResource 2009c)
- Halton and Hamilton Region Conservation Authorities PRMS model (EarthFx 2009)

This model was used to assess the impact of climate change on the GGET municipal water supply systems.

2.4.1 Recent Model Updates

The version of the Tier Three model used to carry out the baseline and climate change scenarios described in the following sections is based on the model developed for the GGET Tier Three Risk Assessment Scenario H1 (Matrix 2017), which includes consideration of transient recharge, future land use, future municipal pumping, and existing non-municipal pumping. This Tier Three model was updated to reflect more recent information within the local WHPA-Q as part of the RMMEP (Matrix 2018) and included updated non-municipal pumping rates and boundary conditions within the local WHPA-Q. This updated model was carried forward for use in this assessment.

2.5 Climate Change Hydrogeology Scenarios

Five predictive scenarios were developed to compare and assess the potential impacts of climate change on water levels within GGET municipal wells, the ability of the Eramosa Intake to withdraw water, and yield from the Glen Collector. These scenarios include one baseline scenario representing past climatic conditions from 1960 to 2005 and four future climate scenarios representing a range of temperature and precipitation variations predicted by selected GCMs (i.e., scenarios 1 to 4; Figure 15).

For each of the five scenarios, the groundwater model described in Section 2.4.1 was updated with a new transient time series of groundwater recharge generated by GAWSER. Each scenario also included a unique time series representing pumping from the Eramosa River intake and injection of that water into the Arkell artificial recharge system. Pumping from the Eramosa River intake was simulated to occur according to the seasonal restrictions, and also according to flow restrictions on the Eramosa River, as outlined in its PTTW.

2.5.1 Predicted Impact on Water Levels in Municipal Water Supply Wells

Figures 19 to 22 show the predicted drawdown for the baseline and four climate change scenarios at the Queensdale, Burke, Bernardi (i.e., Rockwood Well 3), and Park municipal wells. These wells are highlighted as they represent some of the wells predicted to have drawdown during the GGET Tier Three Assessment (Matrix 2017) that approached or exceeded their safe operating level (i.e., “safe additional available drawdown” in Figures 19 to 22). The time period associated with the 1960s drought is shown on Figures 19 to 22, as that time interval represents the greatest amount of drawdown predicted over the 45-year record.

The results of these groundwater scenarios illustrate that the maximum drawdown occurs during baseline climate conditions. Each of the four climate change scenarios shows a progressive reduction in the magnitude of drawdown for all of the wells. This reduction in drawdown is in response to the increase in recharge predicted to occur under future climate conditions. Most of this increased recharge is predicted to occur during the first four months of the each year (Figure 17). While groundwater recharge is predicted to decrease during the summer months and early fall due to higher temperatures, the magnitude of this reduction is small compared to the amount of increased recharge predicted during the winter and spring. As a result, more water is predicted to recharge the groundwater system and buffer the impact of municipal demands. This result indicates that climate change may not pose an additional threat to the GGET municipal water supply wells. However, the predicted drawdown at the Queensdale well is still predicted to exceed its safe operating level under all climate change scenarios and therefore still remains a Significant Drinking Water Threat.

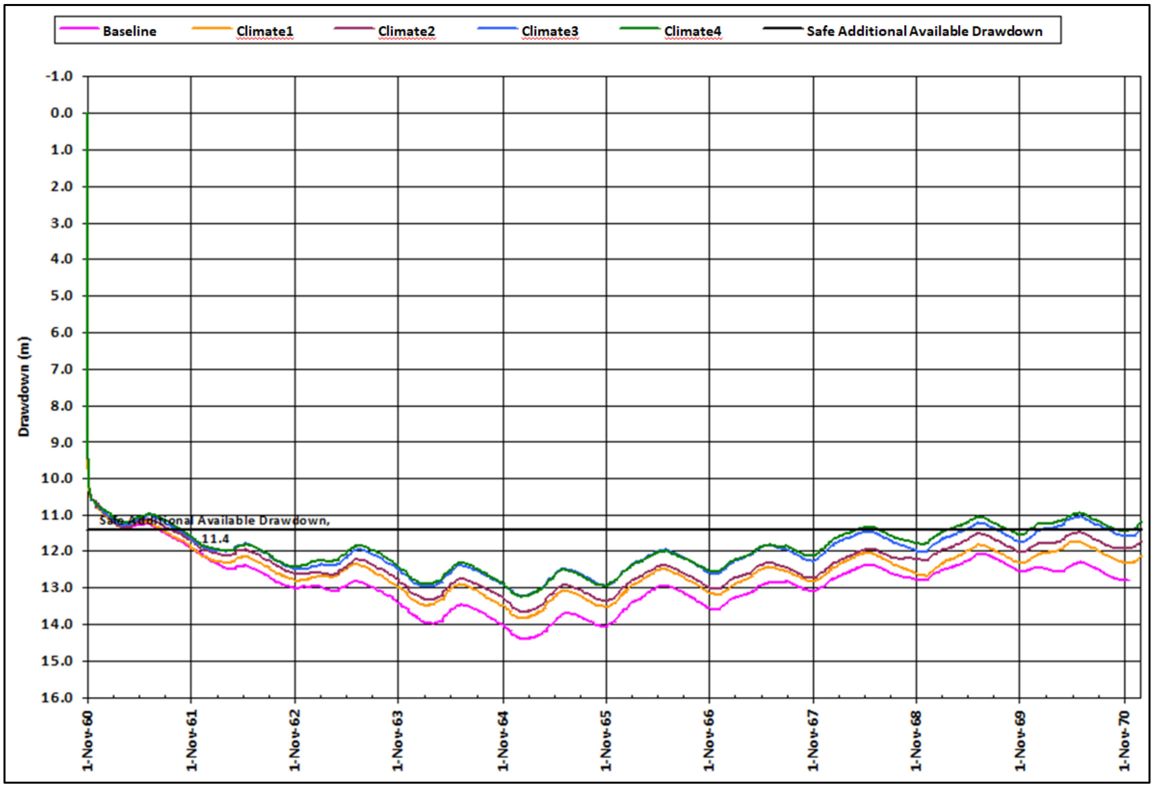

FIGURE 19 Projected Drawdown Under Future Climates, Queensdale Well (2050s versus Baseline)

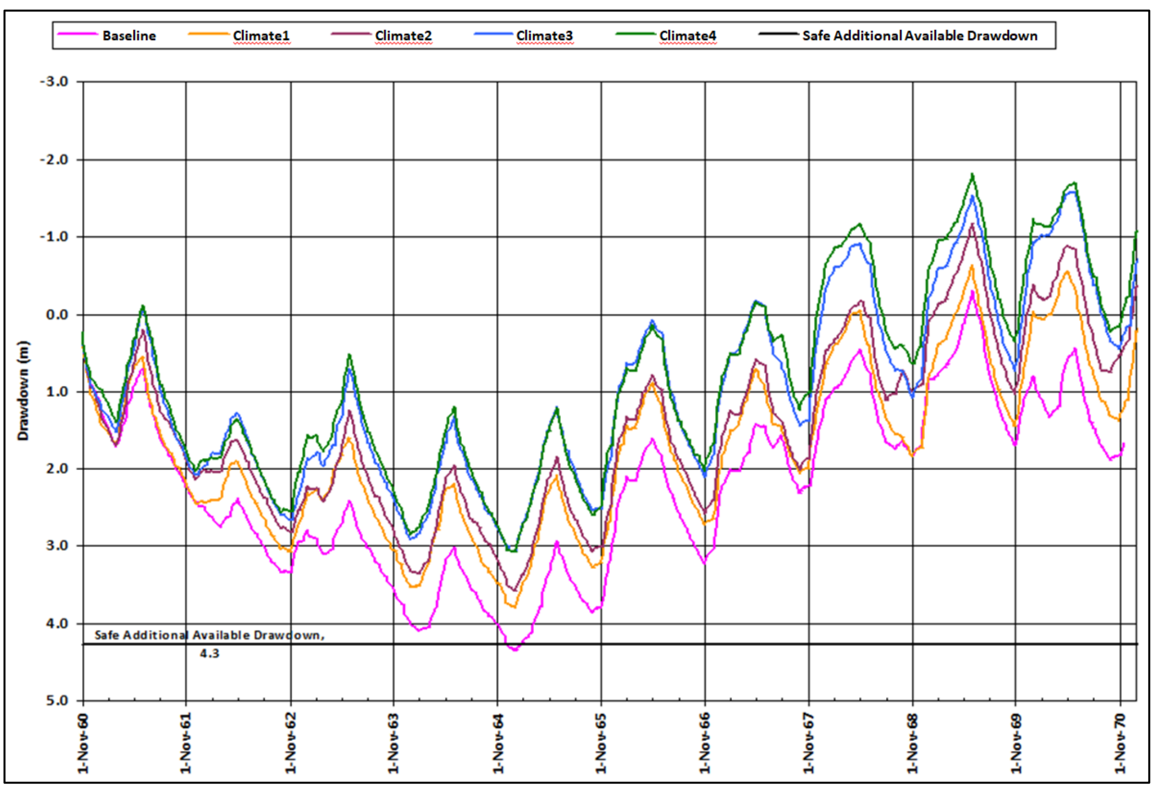

FIGURE 20 Projected Drawdown Under Future Climates, Burke Well (2050s versus Baseline)

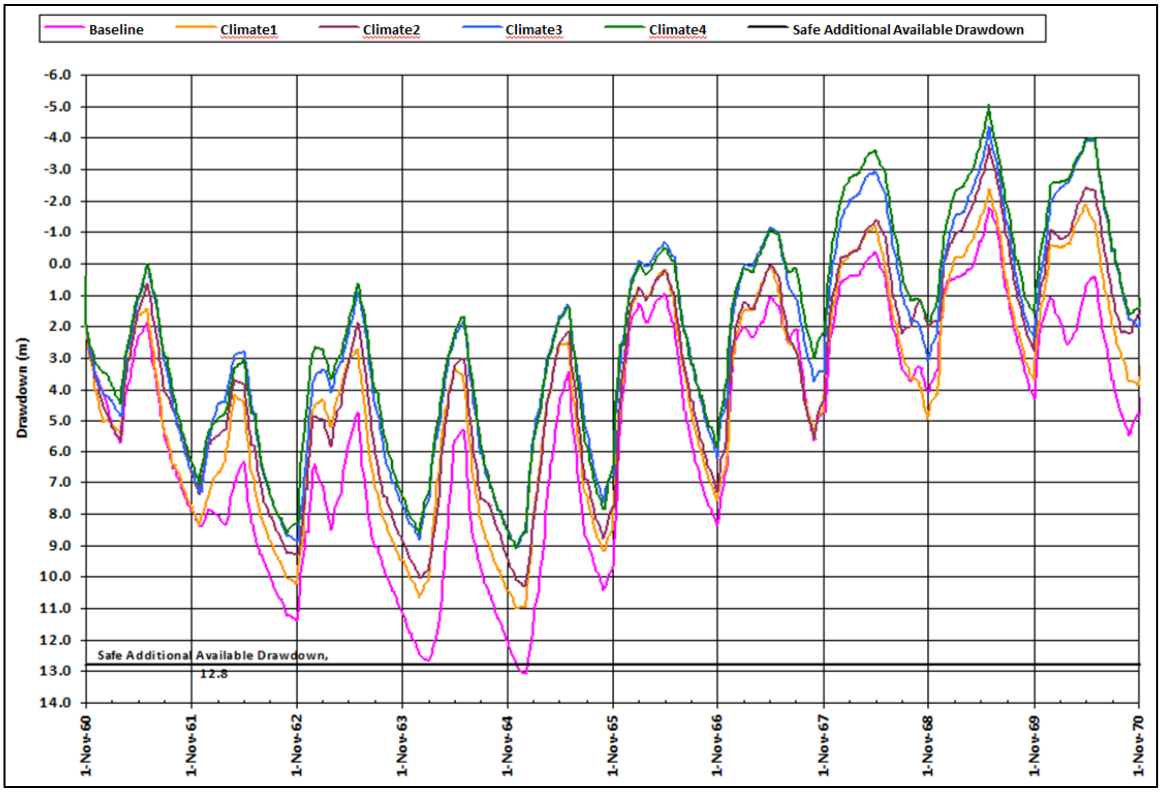

FIGURE 21 Projected Drawdown Under Future Climates, Bernardi Well (2050s versus Baseline)

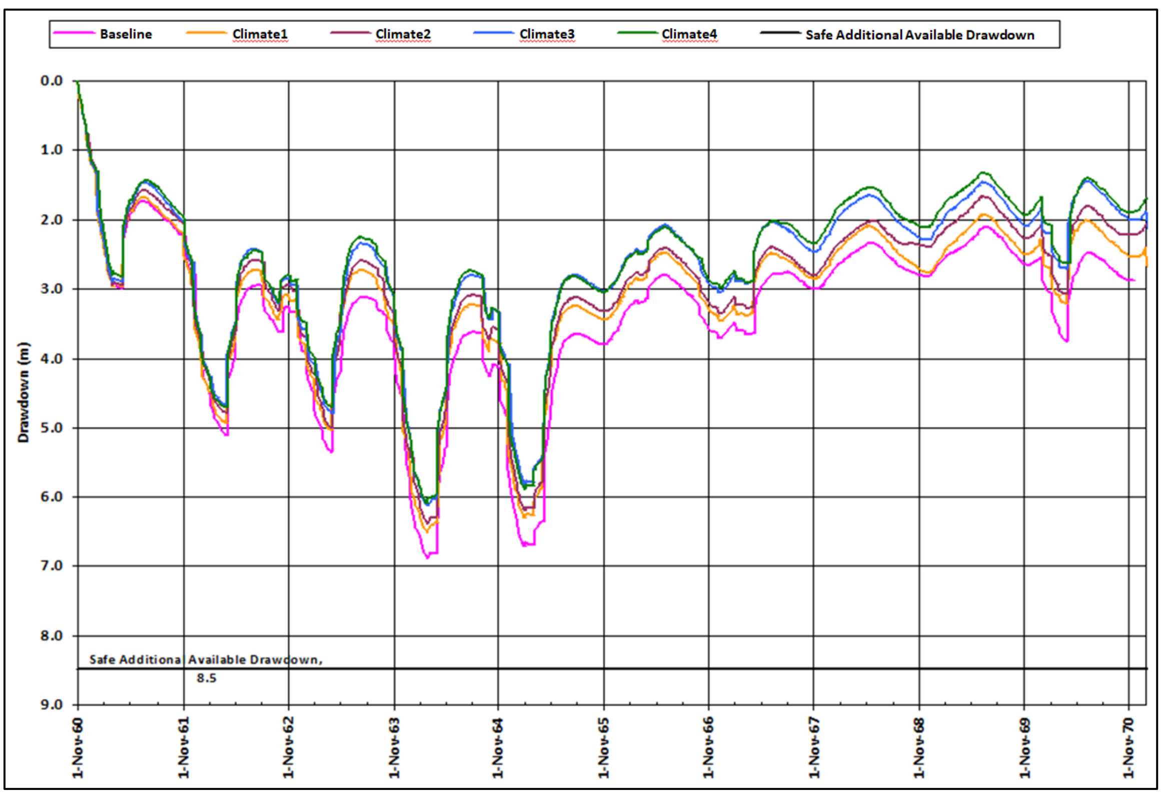

FIGURE 22 Projected Drawdown Under Future Climates, Park Wells (2050s versus Baseline)

2.5.2 Influence on Eramosa River

Table 6 summarizes some typical streamflow statistics for the simulated flow on the Eramosa River at Water Survey of Canada (WSC) gauge 02GA029 near the Eramosa intake, under the baseline and climate change scenarios over a 45 year simulation period (1960-2005). These statistics include the mean annual flow, annual 7-day low flow with a 20-year return period (i.e., 7Q20), and the number of days where the Eramosa River intake cannot pump according to PTTW restrictions. Figure 23 illustrates mean monthly streamflow to evaluate seasonal changes in each scenario. Finally, the range in streamflow variability for each scenario is illustrated using ranked flow analysis on Figure 24 and summarized in Table 7.

TABLE 6 Eramosa River Flow Summary under Future Climates (2050s) and over 45 Year Simulation Period (1960-2005)

Scenario	Mean Annual Flow		7Q20		Number of Days Unable to Pump	
	m^3/s	% Change Compared to Baseline	m^3/s	% Change Compared to Baseline	Number of Days	% Change Compared to Baseline
Baseline (Current Climate)	2.330	0%	0.366	0%	7,298	0%
Climate 1	2.324	-0.3%	0.366	0%	7,393	+1%
Climate 2	2.451	+5%	0.370	+1 %	7,272	-0.4%
Climate 3	2.574	+10%	0.366	0%	7,359	+0.8%
Climate 4	2.553	+10%	0.367	+0.3%	7,294	-0.1%

As summarized in Table 6, the mean annual flow for three of the climate change scenarios is predicted to increase from the baseline case by up to 10%. The decrease in mean annual flow for the remaining scenario is only 0.3%. The increase in mean annual flow is due to the greater amount of flow predicted to occur during the first four months of the year (Figure 23).

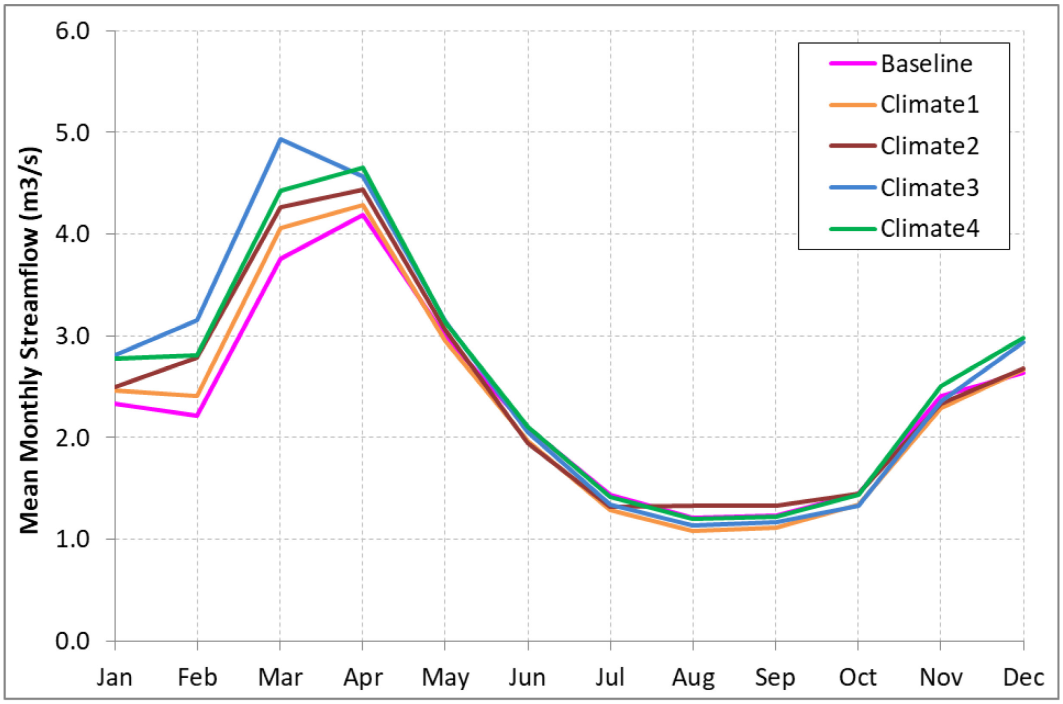

FIGURE 23 Mean Monthly Flow under Future Climates (2050s Versus Baseline)

The 7Q20, which represents low flow conditions, remains similar between all scenarios (Table 6). The relative insensitivity of the model to changes in the 7Q20 may be due to limitations of the model at such low flow rates. The GAWSER model simplifies groundwater discharge processes and as a result there is a greater uncertainty of the model's predictions at this extreme.

Over the 45 year simulation period, the number of days that the Eramosa River intake was predicted to not be able to pump according to the PTTW restrictions varied between climate scenarios (Table 6). Climate change scenario 1 and 3 predicted that there would be more days where the intake would not be able to pump relative to the baseline case (i.e., 95 and 61 more days, respectively). Conversely, climate change scenario 2 and 4 predicted that there would be fewer days where the intake would not be able to pump relative to the baseline case (i.e., 26 and 4 more days, respectively, where it could pump). The range in these results, however, is within 1% of the baseline scenario.

Finally, Figure 24 illustrates the variability of the simulated flow for each scenario using a ranked duration analysis. Table 7 summarizes the ranked flows, where the results are grouped into three categories where Eramosa River flow is exceeded 20%, 50%, and 80% of the time. Table 7 illustrates that streamflow is generally predicted to increase for each future climate scenario in each of the three categories. The exception is for climate change scenario 1 and 3, where flow is predicted to decrease by 6% and 2%, respectively at the 80% level.

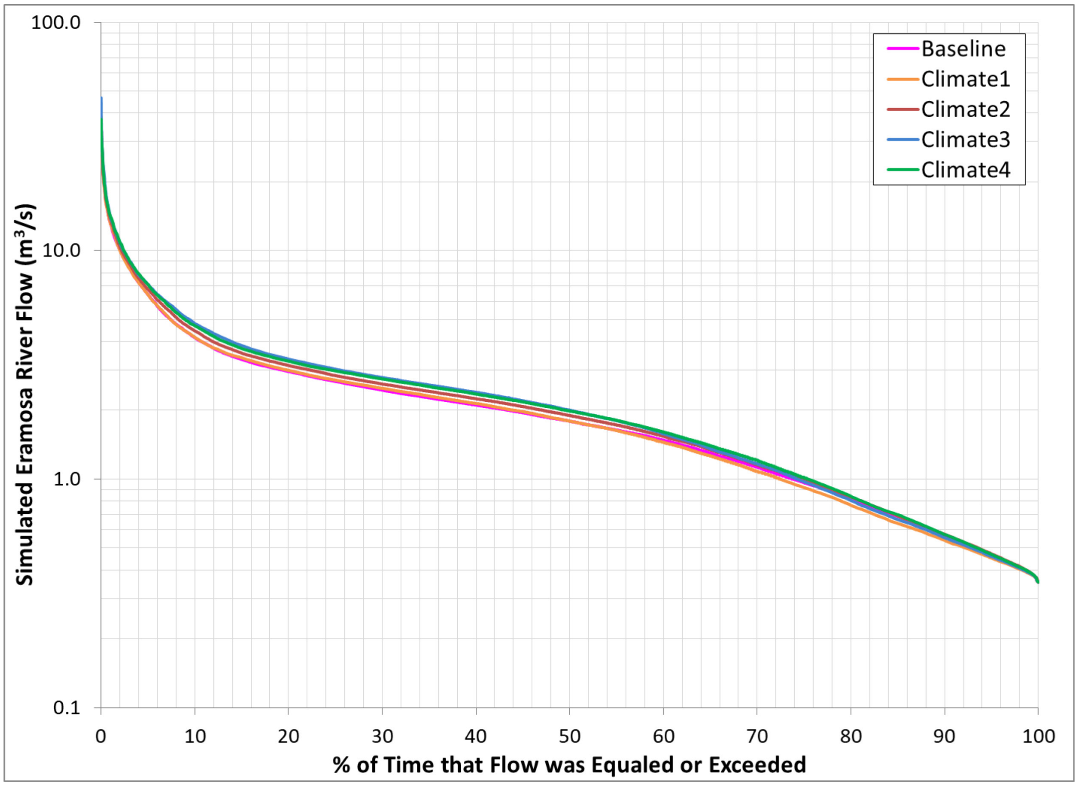

FIGURE 24 Ranked Duration Curves (2050s Versus Baseline)

TABLE 7 Simulated Eramosa River Flow Ranked Duration Analysis under 2050s Climates

Scenario	% Time Where Eramosa River Flow was Equaled or Exceeded	Simulated Eramosa River Flow (m^3/s)	% Change in Eramosa River Flow From Baseline
Baseline (Current Climate)	20	2.96	0%
	50	1.79	0%
	80	0.82	0%
Climate 1	20	2.99	1%
	50	1.79	0%
	80	0.77	-6%
Climate 2	20	3.15	6%
	50	1.90	6%
	80	0.84	2%
Climate 3	20	3.35	13%
	50	2.00	12%
	80	0.81	-2%
Climate 4	20	3.29	11%
	50	1.99	11%
	80	0.84	3%

The future climate scenarios illustrate that average and high streamflow at WSC gauge 02GA029, as reflected by 50 and 20 percentile statistics, is likely to increase according to the assumptions of the climate and hydrologic models. The future climate scenarios also illustrate that there is a potential for lower flows, as reflected by the 80 percentile statistics, to decrease by 2% to 6% as compared to current conditions. The proportion of days where the City of Guelph is unable to pump the Eramosa intake due to its PTTW restrictions is also unlikely to change by more than 1%. These results indicate that the impacts of climate change may result in minimal to no additional risk to the City of Guelph's Eramosa River intake.

2.5.3 Predicted Impact on Yield from the Glen Collector

Table 8 summarizes the predicted average yield of the Glen Collector as predicted by the five groundwater model scenarios. The modelling scenarios predict that the average annual yield from the Glen Collector will increase by 3 to 18% for all climate change scenarios relative to the baseline case. Since the number of days the Eramosa intake can operate is not predicted to change significantly, the increased yield from the Glen Collector is attributed mainly to increased groundwater recharge and shallow groundwater directly feeding the collection system. This result indicates that climate change is not likely to pose additional risk to the yield from the Glen Collector.

TABLE 8 Average Glen Collector Yield Under Future Climates

Scenario	Average Glen Collector Yield (m^3/day)	Comparison to Baseline
Baseline (Current Climate)	7,800	0%
Climate 1	8,115	+3%
Climate 2	8,975	+13%
Climate 3	9,132	+14%
Climate 4	9,614	+18%

3 IPZ-Q THREATS ASSESSMENT

Significant Threats (i.e., consumptive water takings and recharge reduction activities) to water quantity were identified within the largest WHPA-Q during the GGET Tier Three Assessment (Matrix 2017) and further assessed as part of the RMMEP (Matrix 2018). Due to the overlap of the WHPA-Q with the IPZ-Q, and the interconnection of the Eramosa River intake with the municipal groundwater supply system (Section 1.1.2.1), consumptive water takings and recharge reduction activities within the IPZ-Q were also considered Significant Threats as part of the GGET Tier Three Assessment. The following sections provide an evaluation and ranking of these Significant Threats within the IPZ-Q.

3.1 Significant Threats

In total, 12 municipal permitted water takings, 13 non-municipal permitted water takings, 2,671 non-municipal, non-permitted (e.g., domestic) water takings, and 1.04 km^2 of recharge reduction areas (Figure 5) are identified as Significant Threats. The original GGET Tier Three Assessment Report (Matrix, 2017) incorrectly identifies 11 municipal permitted water takings within the IPZ-Q due to the omission of the Glen Collector permit. Domestic takings were omitted from this IPZ-Q assessment as these takings are relatively small. Similarly, areas of potential land use change and associated reduced groundwater recharge are very small in the IPZ-Q and unlikely to have any impact on streamflow and the amount of available water for surface water takings. As a result, the impact of recharge reduction areas will not be considered further.

Permitted takings were originally compiled in 2008 to support the Tier Three Assessment. For the current study, updated PTTWs were obtained for the IPZ-Q, along with recent (i.e., 2015) reported water takings from the Water Taking Reporting System (WTRS) and annual municipal reporting (City of Guelph 2016). A total of 24 active permitted takings were found within the IPZ-Q; however, 5 of these either did not report takings in 2015 or reported zero takings. Three takings were not considered consumptive (i.e., water was returned to the source; Table 9); two of these included the Eden Mills Millpond dam/reservoir (PTTW 5410-8YQNXU) and a transfer pond used for temperature adjustment (5200-7VSP2M; Baker 2017, Pers. Comm.). The Eramosa intake was also considered non-consumptive as the portion of water that artificially infiltrates and gets captured by the Glen Collector is considered 100% consumptive for the Glen Collector. PTTWs that did report takings in 2015 included 12 municipal takings and 10 non-municipal takings (Table 9).

Table 9 also presents the consumptive rates for each taking using the 2015 average annual rate and the consumptive use factor. The consumptive rates represent the proportion of water that is estimated to be withdrawn and not returned to the original source. The consumptive use factors applied are consistent with those used in the Tier Three Assessment (Matrix 2017).

TABLE 9 Permitted Consumptive Water Use in the IPZ-Q (2017 Update)

Type of PTTW	Municipal Taking Name or Non-Municipal PTTW #	Maximum Permitted Rate (m^3/day)	2015 WTRS Annual Average Rate (m^3/day)	Specific Purpose	GW or SW Source[1]	Consumptive Use Factor	2015 Consumptive Rate (m^3/day)	2015 Consumptive Rate (m^3/s)
Municipal	Arkell 1	3,273	94	Municipal	GW	100%	94	0.001
	Arkell 6	9,600[2]	5,484	Municipal	GW	100%	5,484	0.064
	Arkell 7	9,600[2]	6,708	Municipal	GW	100%	6,708	0.078
	Arkell 8	9,600[2]	1,289	Municipal	GW	100%	1,289	0.015
	Arkell 14	9,600[2]	4,938	Municipal	GW	100%	4,938	0.057
	Arkell 15	9,600[2]	2,036	Municipal	GW	100%	2,036	0.024
	Eramosa Intake	9,092 to 31,822[3]	4,829	Municipal	SW	0%	0	0
	Glen Collector	25,000	8,597	Municipal	GW	100%	8,597	0.100
	Rockwood 1	1,965[4]	314	Municipal	GW	100%	314	0.004
	Rockwood 2	1,965[4]	319	Municipal	GW	100%	319	0.004
	Rockwood 3	1,310	364	Municipal	GW	100%	364	0.004
	Rockwood 4	1,310	0	Municipal	GW	100%	0	0
Non-Municipal	2478-8K8P6P	654	34	Other - Agricultural	GW	85%	29	0.0003
	2478-8K8P6P	654	0	Other - Agricultural	GW	85%	0	0
	5200-7VSP2M	1,310	0[5]	Aquaculture	SW + GW	0%[5]	0	0
	5200-7VSP2M	1	0	Aquaculture	SW + GW	100%	0	0
	5200-7VSP2M	2,620	3,028	Aquaculture	SW + GW	100%	3,028	0.035
	3716-8UZMCU	1,113	215	Bottled Water	GW	100%	215	0.003
	2807-96ZRCW	654	142	Golf Course Irrigation	GW	85%	121	0.0014
	2807-96ZRCW	1,308	241	Golf Course Irrigation	GW	85%	205	0.0024
	6246-9VMQ2B	238	12	Golf Course Irrigation	GW	85%	10	0.0001
	8475-96PPX4	150	19	Other - Industrial	GW	100%	19	0.0002
	5410-8YQNXU	254,000	0	Dams and Reservoirs	SW	0%	0	0
	4621-8K7KFK	5,448	0	Other - Agricultural	GW	85%	0	0

[1]GW = Groundwater, SW = Surface Water
[2]Each well is individually permitted up to 9,600 m^3/day; however, the combined permitted rate is 28,800 m^3/day
[3] Maximum permitted rate varies seasonally and is dependent on maintaining flows in the Eramosa River and downstream along the Speed River for waste water assimilation
[4]Each well is individually permitted up to 1,965 m^3/day; however, the combined permitted rate is 1,965 m^3/day
[5] Takings were reported; however, it is a transfer pond used for temperature adjustment ahead of augmentation. MECP recommends 0 m^3/day.

3.2 Assessment of Consumptive Takings

Total 2015 municipal consumptive takings in the IPZ-Q are approximately 0.349 m^3/s (Table 10). Of that, 0.238 m^3/s is withdrawn by the Arkell wells, 0.100 m^3/s is withdrawn from the Glen Collector, and 0.012 m^3/s is withdrawn by the Rockwood Wells (Table 10). Total non-municipal consumptive takings in the IPZ-Q are approximately 0.042 m^3/s.

TABLE 10 Simulated Impact of Municipal Takings on Groundwater Discharge to Eramosa River

Permitted Taking Threat	2015 Consumptive Rate (m^3/s)	Estimated Impact on Average Streamflow at Gauge 02GA029 (m^3/s)	Rank
Total Municipal	**0.349**	**0.245**	**-**
City of Guelph Arkell Wells (1, 6, 7, 8, 14, and 15)	0.238	0.148	1
City of Guelph Glen Collector	0.100	0.086	2
Township of Guelph/Eramosa Rockwood Wells (1, 2, 3, and 4)	0.012	0.011	4
Total Non-municipal (12 PTTW)	**0.042**	**0.042**	**3**

The GGET Tier Three model was used to evaluate the relative potential impact of the municipal consumptive takings on average streamflow at the Eramosa Above Guelph WSC streamflow gauge (02GA029). The model was run with the municipal wells pumping at 2015 rates and with zero pumping, and the reduction in groundwater discharge to the Eramosa River gauge due to pumping was calculated (Table 10). Since the Glen Collector is a passive groundwater collection system, this feature is represented in the model by constant head boundary conditions. The change in groundwater discharge to the Eramosa River gauge due to operation of the Glen Collector was assessed by turning these boundary conditions on and off in the model. Due to the small magnitude, and for the purposes of this assessment, the impact of non-municipal takings were assessed as a single group and conservatively assumed to be equal to their estimated consumptive rate (Table 10).

The total potential influence of municipal and non-municipal takings on streamflow in the Eramosa River at Gauge 02GA029 is a reduction in flow of 0.287 m^3/s (Table 10). The amount represents approximately 12% of the mean annual flow (2.3 m^3/s) and approximately 67% of the threshold streamflow established for the City's permitted water taking at the municipal intake (0.43 m^3/s). Within this total, the impact of permitted municipal pumping rates represents 85% of the total potential impact of permitted water takings on the Eramosa River intake.

Table 10 summarizes the relative risk and ranking for each of the above groups of water takings based on the magnitude of the predicted reduction in streamflow in the Eramosa River. The municipal and non-municipal permitted takings were ranked as follows:

Rank 1 – Arkell Wells. The group of Arkell Wells have the highest predicted influence on the groundwater discharge contribution to baseflow in the Eramosa River (0.148 m^3/s) and therefore the highest relative risk.

Rank 2 - Glen Collector. The Glen Collector has a relative influence of 0.086 m^3/s on baseflow in the Eramosa River and therefore is the second highest relative risk. Most of the water collected by the Glen Collector is sourced by water from the Eramosa Intake, and this water would not be pumped should the City not be able to meet its PTTW requirements.

Rank 3 – Non-municipal PTTWs. The non-municipal permits have an estimated influence of 0.042 m^3/s on baseflow in the Eramosa River, and represent the third highest risk.

Rank 4 – Rockwood Wells. The Rockwood Wells have an estimated influence of 0.011 m^3/s on groundwater discharge into the Eramosa River and represent the fourth highest risk.

4 CONCLUSIONS AND RECOMMENDATIONS

Two assessments were carried out in support of the RMMEP and Water Quantity Policy Study previously conducted for the Guelph-Guelph/Eramosa municipal water supply systems (Matrix 2018) including: an assessment of potential impacts due to future climate change and an assessment of potential impacts due to permitted water takings within the IPZ-Q.

To complete the climate change assessment, future climate datasets were compiled and used in conjunction with a spreadsheet-based water balance model and GAWSER hydrology model to assess how future climates might change the hydrology in the area surrounding the Guelph-Guelph/Eramosa municipal water supply systems. Changes in groundwater recharge and flow in the Eramosa River due to climate change, as predicted by GAWSER, were input into the City of Guelph and Township of Guelph/Eramosa Tier Three groundwater flow model to assess the impact of future climates on water levels in municipal wells, flow in the Eramosa River, and yield from the Glen Collector. The simulated climate change results for the 2050 period suggested that:

- Climate change does not pose an additional threat to the GGET municipal water supply wells due to predicted increase in groundwater recharge. The combination of GCM and RCM models suggest that groundwater recharge rates will increase gradually over time.

- Climate change may result in minimal to no additional risk to the City of Guelph’s Eramosa River intake due to:

    - predictions that streamflow is likely to increase in the future
    - the proportion of days where the Eramosa intake may not be able to pump is unlikely to change by more than 1%

- Climate change may not pose an additional risk to the yield from the Glen Collector due to predicted increase in groundwater recharge.

These results are based on the modelling approach employed, and the GCMs and RCM selected for this assessment. These water budget models and future climate datasets represent the state of the practice at the time of this assessment. As described earlier in this report, the future climate models and water budget models have uncertainty, and the approach used to address this uncertainty is the completion of multiple scenarios providing a range of plausible outcomes. It is recommended that this modelling be updated approximately every five years to reflect revisions in water budget models, water demand, and climate change models.

To complete an assessment of the potential impacts due to permitted water takings within the IPZ-Q, PTTWs originally compiled for the Tier Three Assessment were updated in the IPZ-Q and 2015 consumptive municipal and non-municipal demands were estimated. The Tier Three model was used to predict the impact of the municipal PTTWs on streamflow at the Eramosa Above Guelph streamflow gauge and groups of municipal takings were ranked according to the magnitude of their predicted impact. Non-municipal permitted takings were considered as a single group and the impact to flow on the Eramosa River was conservatively assumed to be equivalent to the total 2015 non-municipal consumptive rate. The City of Guelph Arkell wells and Glen Collector were ranked 1 and 2, respectively; the group of non-municipal takings were ranked 3, and the Rockwood Wells were ranked 4.

As a result of these findings, it is recommended that the City of Guelph maintain its current groundwater and surface water monitoring program to ensure that the hydrologic regime in Eramosa River is maintained in accordance with the requirements of its PTTW. The modelling results also indicate that there may be a potential to optimize the artificial recharge and collection system operated at Arkell Springs. This optimization may help ensure that the system operates as efficiently as possible, maximizing the capture of water pumped from the river.

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APPENDIX A
Grand River Conservation Authority (GRCA) Climate Change Analysis (RSI 2016)

RISK SCIENCES INTERNATIONAL

REPORT

Grand River Conservation Authority (GRCA)

Climate Change Analysis

Prepared for:
Matrix Solutions Inc

March 16 2016

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Contents

Two Attached Spreadsheet Document with this report

1. Requirements and Deliverables

Risk Sciences International (RSI) is providing the climatology and climate change analyses for this study using quality controlled and peer reviewed climate change model outputs from the RSI climate analytical system. Inclusion of the most recent 2013 AR5 climate change model results will help in providing an up-to-date assessment of watershed vulnerabilities to guide planning for a more robust and resilient water resource system into the future.

The climate deliverables for this project require baseline climate and climate change differences (deltas) representative of the central portion of the GRCA sub-watershed for the 2050s, along with background and documentation of the approach taken.

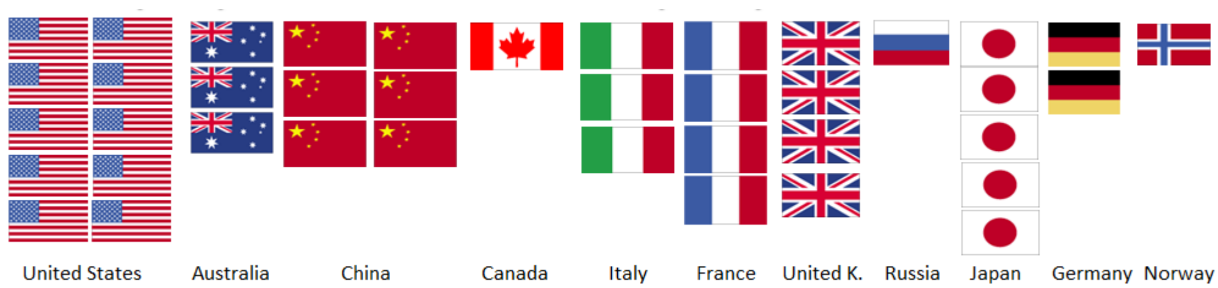
This work has been enabled through analyses of the 2013 IPCC released climate change models (40 AR5 GCMs), which have undergone additional quality control, and are archived in the RSI analytical system. The analyses also include at least one RCM output for comparison to the selected ensemble of Global Climate Models (GCMs). Key elements of the report include:

- Summary of output from each of the 2013 AR5 GCMs, represented as the mean annual change in temperature and precipitation
- From the entire set of models, rankings with respect to mean annual temperature and precipitation, and indications of the 5th, 25th, 50th, 75th and 95th percentile projections for each of these parameters;
- For each of the selected GCMs (5X2 = 10), provide the monthly changes in temperature and precipitation from the most recent observed and/or interpolated baseline or Normals period (e.g. 1981-2010 or a different period, as appropriate) to the 2050s period.
- Output from at least one of the RCMs, which may be included within or additional to the selected GCMs
- Baseline climate data as well as the future projected climate fields annually and monthly.

2. Climate Change Background

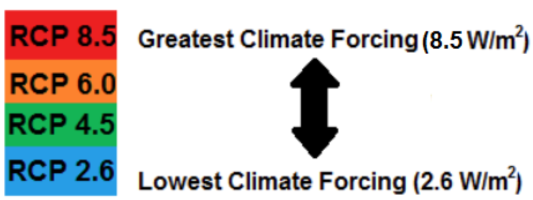
Climate change is defined as the longer-term change in atmospheric conditions of temperature, precipitation, etc., whether by natural or human-generated sources. It can affect both average conditions and extreme events. Climate change has occurred over all of Earth's history resulting in both warmer and cooler periods of various lengths. The current climate change discussion has focused on the most recent 100 years or so where a gradual and accelerated increase in global temperature has been observed, with regional differences, including the Grand River Conservation Authority territory. This global increase has been attributed predominantly to human-influence arising from the burning of fossil fuels which adds to the atmospheric concentration of greenhouse gases (predominantly carbon dioxide and methane). Global mean temperature has increased 0.85°C from 1880 to 2012 (IPCC,2013), whereas within Canada the temperature has increased by 1.6°C since 1948 to 2013 – much higher than the global average, with the greatest increase found in the far north (Gov. Canada,2015). The observed change is completely consistent with modelled climate output.

The Intergovernmental Panel on Climate Change (IPCC) is considered the most robust source of climate change science guidance, since it consists of thousands of contributing scientists from across the globe. The IPCC reports continue to provide the best science-based information on projected climate change assembled from the best climate researchers worldwide. Since the second IPCC Assessment released in 1995, the number of contributing international climate modelling centres, models, and their complexity, have increased significantly – from 11 models to the current 40 used in the most recent AR5 Assessment as shown below (RSI graphic).



With increased computing power, better refinement of atmospheric phenomena have been incorporated, and model spatial and temporal resolution has improved (Kharin et al. 2013). The development of regional climate models (even higher resolution) continues, although there are far fewer of these than global climate models. An important outcome of this increase in model availability is the ability to produce projections of future climate based upon an 'ensemble' of many models versus the use of single or only a few models. The use of multiple models to generate a 'best estimate' of climate change is preferred over a single model outcome and this approach is recommended by the IPCC. Research has indicated that the use of multi-model ensembles is preferable to the selection of a single or few individual models since each model can contain inherent biases and weaknesses (IPCC-TGICA, 2007, Tebaldi and Knutti, 2007). The use of the ensemble projection from the family of global modelling centres (40 models and dozens of estimates) is likely the most reliable estimate of climate change projections on a large scale (Gleckler et al, 2008). Environment Canada contributes to this IPCC ensemble with its own developed model (CanESM2). This RSI report considers all models and model runs available for the most recent assessment (AR5).

A new initiative in the IPCC AR5 is the introduction of RCPs (Representative Concentration Pathways). They represent a range of possible projection outcomes which depend upon different degrees of atmospheric warming. The lowest RCP 2.6, represents an increase of 2.6 W/m^2 to the system, while the highest RCP 8.5 represents an increase of 8.5 W/m^2 of energy. This range encompasses the best estimate of what is possible under a small perturbation situation (2.6) and under a large increase in warming (8.5). It is unknown which of the RCPs will apply in the future. However, it is important to note that historically, the GHG emissions have followed the highest (8.5) pathway (see chart below). Of course the magnitude of future climate change is greatly influenced by the forcing scenario selected.



With each subsequent IPCC Assessment report, the evidence of climate change builds and increasingly points towards greater confidence that human-kind is having and will continue to influence our future climate, from warming, to extreme events, to sea-level rise to melting sea-ice. Confidence wording in the IPCC documents are characterized by the use of specific terms such as 'very likely' or 'virtually certain', where in previous reports changes may have been referred to as 'likely'. There has been a gradual increase in confidence of the projections from climate models over time. Some of the main points from the most recent IPCC AR5 report (IPCC, 2013) are identified below:

- Warming of the climate system is **unequivocal**, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.

- The atmospheric concentrations of carbon dioxide (CO2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years.

- Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.

- Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

- Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing.

- Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions.

- Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.

- Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

- Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

Among the most recent IPCC reports was the addition of a separate document on climate extremes, the IPCC SREX document (IPCC-SREX, 2012). In addition to changes in the mean climate, extreme climate events will also be impacted, and in many cases the changes in the extremes are expected to be greater than the changes in the mean.

Of particular interest are the following conclusions from the extremes report (IPCC-SREX, 2012):

- It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale.

- It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas.

- It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.

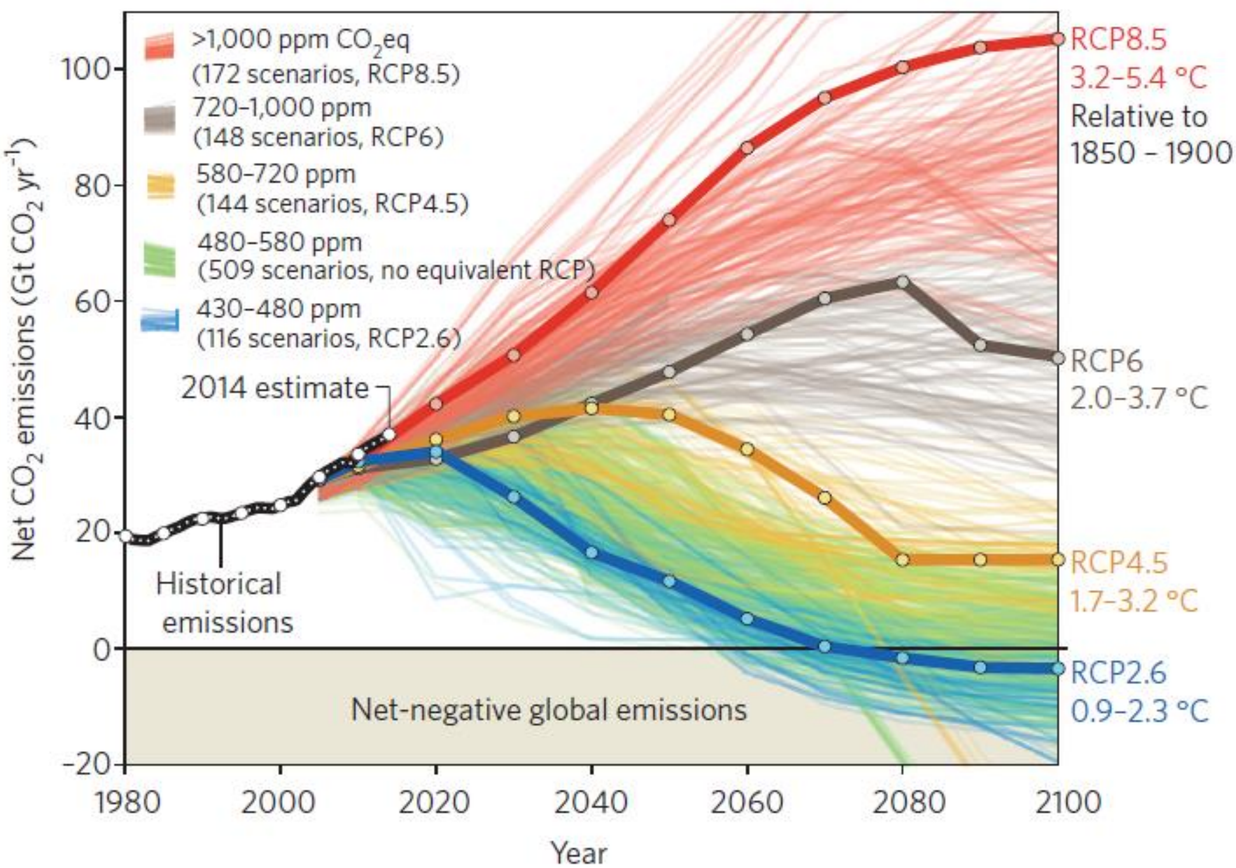
- Extreme events will have greater impacts on sectors with closer links to climate, such as water, agriculture and food security, forestry, health, and tourism.

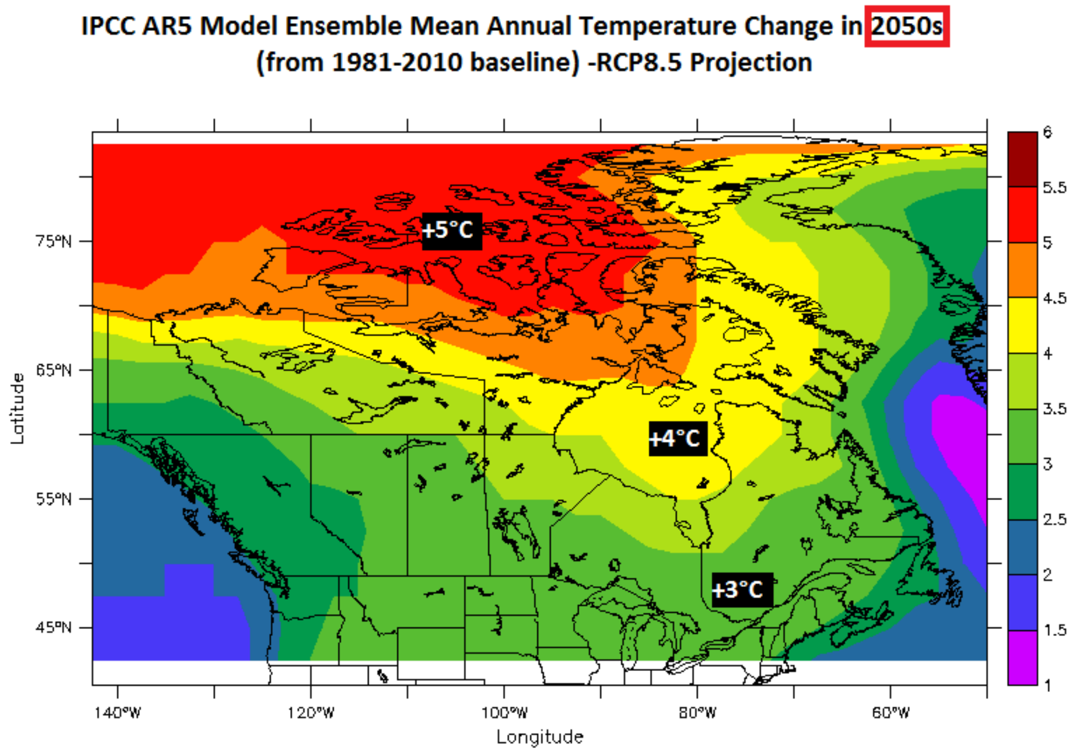
- Attribution of single extreme events to anthropogenic climate change is challenging.

3. Projections of Future Climate

3.1. Mean Climate Change

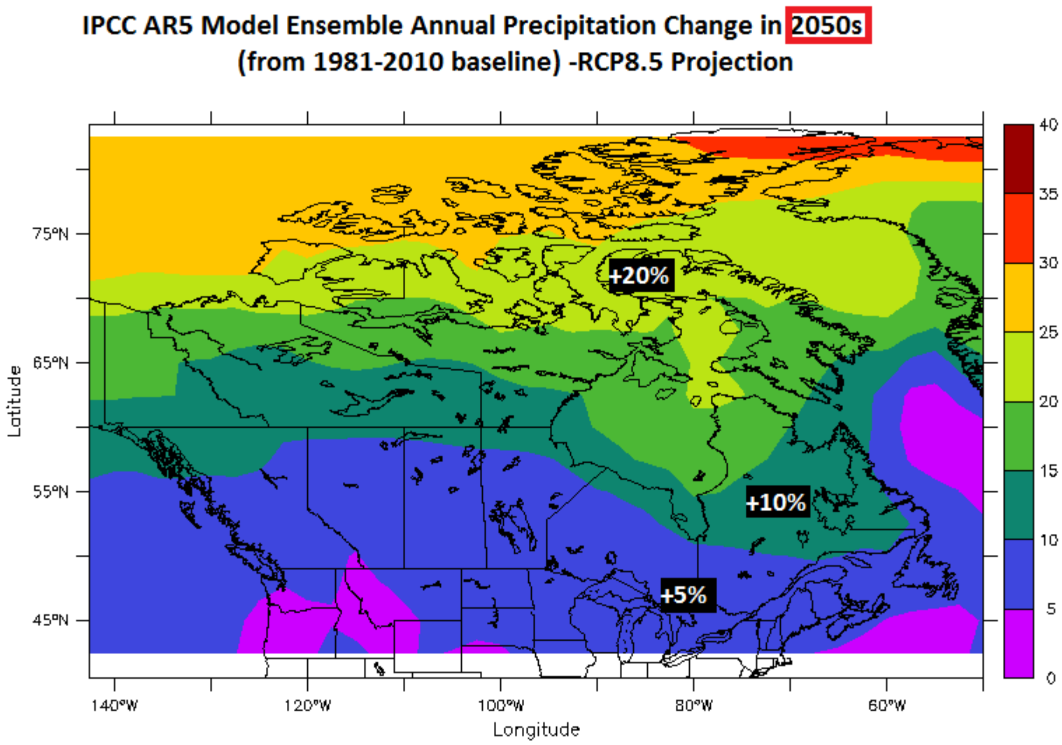
Projected climatic change over Canada can be shown by using the assemblage of all models that contributed to the last IPCC assessment, with data available through the IPCC data portal. In Canada, the greatest temperature increases are expected north of 60 degrees latitude, where by the 2050s period (2041-2070), the average annual temperature is projected to be up to 5 degrees warmer than current conditions according to the current-trajectory RCP8.5 forcing pathway. In the GRCA, projected annual change is smaller but still significant under the projections. The RCP8.5 projections are shown below for Canada. The other RCPs show smaller changes than those presented, but again, seem less likely given the current emissions trajectory. SO although there are multiple RCPs, for this report, only the RCP8.5 trajectory is considered since this the pathway historically followed as seen below, up to 2014. Even with an immediate agreement on GHG reduction globally or even an immediate cut to zero GHG emissions, warming is already committed due to the long residence time of these gases (Figure from Fuss, 2014).





Similarly, average ensemble projections of precipitation change over the same period and RCP is shown below. Again, the greatest percentage change in annual precipitation is envisioned in Canadas Arctic region, with increases of up to 35% from current levels. In the GRCA area, annual precipitation changes from the ensemble of models is near 5%, but this mean change does not consider reflect the nature of seasonality or extreme precipitation.

These are mean annual changes, and it is important to note that there are seasonal differences in the changes shown, with some seasons showing greater change than others. These seasonal changes can have profound effects on water supply and availability through both precipitation input and evapotranspiration changes (the water balance between input and output).



3.2. Changes in Extreme Precipitation

Changes in extremes of precipitation such as single-day rainfall and rainfall intensities (mm/h) are expected to be even greater than the mean changes shown here, and indeed in the south high-intensity rainfall events have been seen recently, although there is not yet any statistically significant trend in these short-term events (Shephard, 2014). This could simply be due to the short record length of monitoring rainfall intensities through the Environment Canada Intensity-Duration-Frequency observation network of tipping bucket rain-gauges.

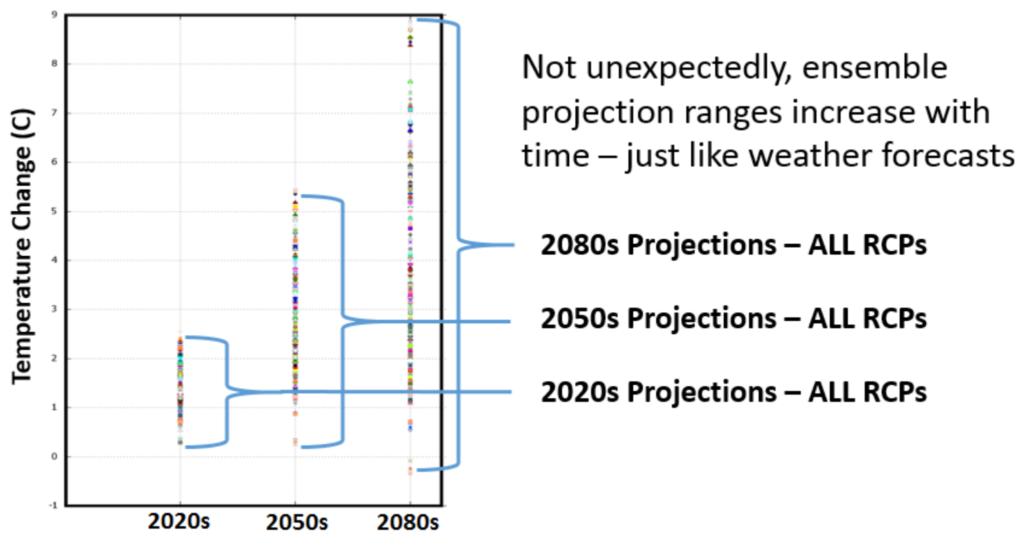
Future projections indicate that extremes will increase going forward with extreme event occurrence becoming twice as frequent as they are currently. This means an extreme event which occurred on average every 50 years would be expected every 25, and a 1 in 100 year event would occur on average every 50 years.

3.3. Uncertainty

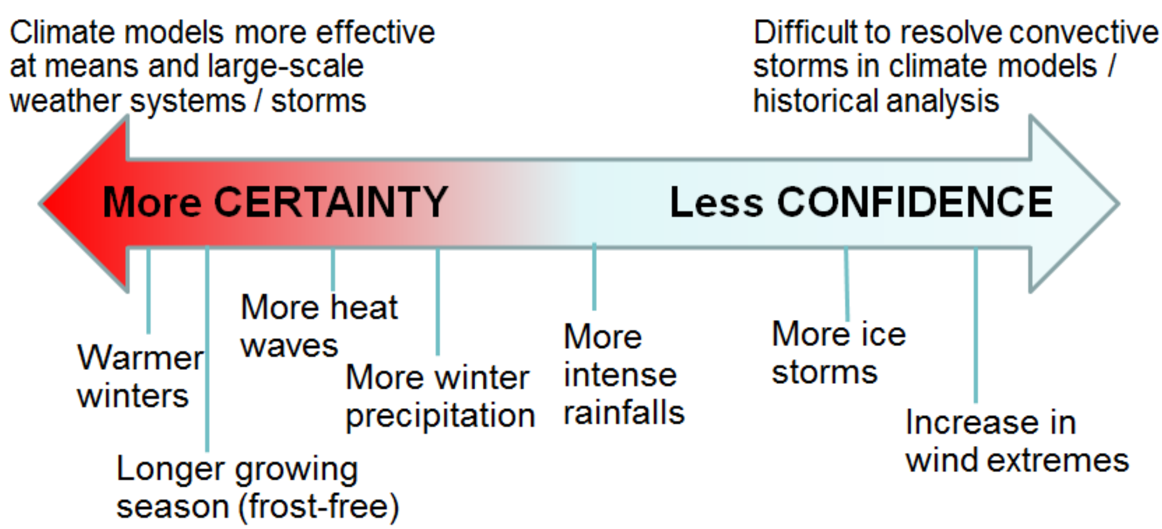
Although single extreme events are difficult to attribute directly to climate change, studies have shown that temperature-related events (heat waves) are very likely linked to changing climate.

Precipitation related extremes are more difficult to directly link, but these types of events are consistent with model projections going forward (Herring, et al, 2015).

Beyond the 2050s, these changes are projected to increase even more – although uncertainty from the models also increases going forward for all variables. This graphic shows the increase in model projected outcomes for temperature for all RCP options combined (RSI graphic).

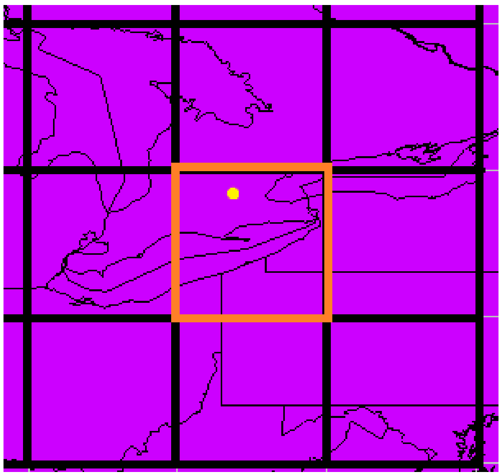


Different model output projections have varying levels of uncertainty – for example, model projected temperature changes are more certain than precipitation or wind. A proxy measure of this uncertainty is the range of model projected values – where the projection range between models is smaller, there is expected to be greater confidence in the value, whereas when model projections are highly variable, confidence in that parameter is lessened. Some relative confidence in model projected variables is shown below (RSI graphic).

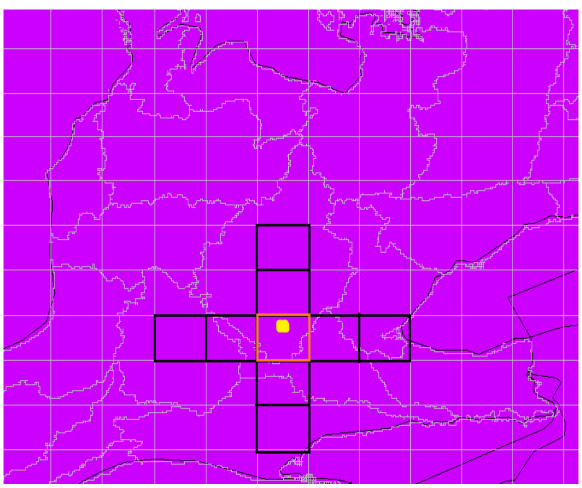


3.4. Procedure

The remainder of this report considers an investigation of climate change projections for the GRCA territory as assessed from the ensemble of AR5 GCM models. RSI has regridded all the GCM projection models used in this report to a common grid size as shown (approximately 150 x 150 km). In addition to this analysis of GCMs, time series data for the Canadian Regional Climate Model for this location is provided separately in its original resolution.



Map showing location of GCM grid cell considered for this report (highlighted) and the location of W-W-Airport



Map showing location of the RCM (CanRCM4 -25km) grid cell from which projections will be obtained (highlighted) and the location of W-W-Airport

From all of the GCM temperature and precipitation changes (deltas) between the baseline (1981-2010) and future period (2050s), summary statistics are provided. Based upon the deltas, the 5 models closest to the entire ensemble 5th, 25th, 50th, 75th and 95th percentiles for annual temperature and the 5 models closest to the entire ensemble 5th, 25th, 50th, 75th and 95th percentiles for precipitation are then used to provide monthly change fields for further hydrological model analysis (10 model outputs). This information is included on the attached spreadsheet.

4. Climate Model Ensemble Change and Individual Model Selection

Climate is simply defined as 'long-term weather'. It is the average weather conditions for a long enough period to average out natural fluctuations. The typical climatological normal period (or 'Normal') is considered by convention to be 30 years. The most recent climate normal period is 1981-2010. The future projection period considered for this report is the 2050s (2041-2070). The 'change' or 'delta' then represents the difference in temperature and precipitation between these 2 periods.

Using a 'delta' technique, the actual historical values of the models aren't used, since we only consider the CHANGE between the historical period and the future period of interest. It is this CHANGE or DELTA, which can then added to the real observations to obtain the future estimates or for input into a hydrological model. In this way, any model bias from historical observations is removed and only the signal is used. Other more complex techniques including statistical downscaling may be employed, but generally this process requires considerable expertise and customized input datasets which are not available for all models.

Comparison of Model 'DELTA' Values for Annual Temperature (top) and Annual Precipitation (bottom) from the entire Ensemble of GCMs (baseline 1981-2010, future period 2050s).

TOTAL ENSEMBLE STATISTICS FOR TEMPERATURE DELTA

(in degrees C change)	5th Perc	2.20728
	25th Perc	2.8146
	50th Perc	3.1347
	75th Perc	3.6101
	95th Perc	4.34302

TOTAL ENSEMBLE STATISTICS FOR PRECIPITATION DELTA

(in percent change)	5th Perc	-0.03356
	25th Perc	4.1196
	50th Perc	6.6161
	75th Perc	9.616
	95th Perc	13.25266

Models Obtained Most Closely Matching the Percentiles above:

Temperature:

FIO-ESM(Run 1)	RCP8.5	2.2328	(APPROX - 5TH PERCENTILE)
CCSM4(Run 1)	RCP8.5	2.8164	(APPROX - 25TH PERCENTILE)
CSIRO-Mk3-6-0(Run 10)	RCP8.5	3.1355	(APPROX - 50TH PERCENTILE)
CESM1-CAM5(Run 2)	RCP8.5	3.6101	(APPROX - 75TH PERCENTILE)
MIROC-ESM(Run 1)	RCP8.5	4.3289	(APPROX - 95TH PERCENTILE)

Precipitation:

IPSL-CM5A-MR(Run 1)	RCP8.5	0.0794	(APPROX - 5TH PERCENTILE)
CNRM-CM5(Run 1)	RCP8.5	4.1196	(APPROX - 25TH PERCENTILE)
NorESM1-M(Run 1)	RCP8.5	6.6161	(APPROX - 50TH PERCENTILE)
ACCESS1-3(Run 1)	RCP8.5	9.616	(APPROX - 75TH PERCENTILE)
CMCC-CESM(Run 1)	RCP8.5	12.8213	(APPROX - 95TH PERCENTILE)

5. Climate Model Projection Results for the 2050s period (years 2041-2070)

The detailed projection results for temperature and precipitation for the selected 10 models above, and the Canadian regional model (CanRCM4 at both 25 km resolution), are provided in the attached excel spreadsheets.

6. Conclusions

RSI has provided in this report and accompanying spreadsheet a comprehensive survey of projected temperature and precipitation projections from a baseline condition of 1981-2010 for the 2050s, as indicated by the full AR5 model ensemble. From this ranking, the 5 models for temperature and precipitation for the percentile values required are further investigated. From the resulting 10 models, monthly deltas for both temperature and precipitation are provided for the grid cell representing the K-W Airport location.

Projected monthly deltas from the Canadian RCM (CanRCM4) at 25km are provided in a separate spreadsheet for the grid cell representing the K-W Airport location.

Background data on the models used for the study and emissions assumptions, the reason behind the selection of the single RCP8.5 here, best practices for model ensembles and the delta technique employed here are described. Given a suitable baseline historical climatology of temperature and precipitation, the monthly changes provided here could be used to adjust the historical dataset to provide future projected datasets using whichever percentile adjustment might be of interest. This could range from a 'low' estimate of the 5th percentile of the model ensemble, through to the 'extreme' estimate of the 95th percentile of all models.

It should be noted however, that extremes of both temperature and precipitation are projected to increase a greater amount than simple monthly means. So if anything the current projections of mean change are most likely conservative. In fact, extreme precipitation events for southern Ontario under a warmer, more vigorous water cycle with greater convection is expected to produce larger short-duration precipitation events beyond that shown here. Certainly the values presented are representative of longer (monthly) expected change, but shorter duration (day or hourly events), are expected to increase even more. Further analysis of precipitation extremes is an ongoing, unresolved research area in climate change with a large degree of uncertainty.

Although extreme events may be increasing there is reasonable expectation from the ensemble that summertime precipitation totals will remain steady or perhaps even decrease for the GRCA area. Combined with warmer summer temperatures and higher evaporation, with longer dry periods between more extreme events, this could produce a larger challenge for water management in that season.

Appendix ONE:
All IPCC AR5 (Fifth Assessment) Models, Organizations and Country of Origin:

Model Name	Organization	Country	Organization Details
ACCESS1-0	CSIRO-BOM	Australia	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
ACCESS1-3	CSIRO-BOM	Australia	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
BCC-CSM1-1	BCC	China	Beijing Climate Center, China Meteorological Administration
BCC-CSM1-1-M	BCC	China	Beijing Climate Center, China Meteorological Administration
BNU-ESM	GCESS	China	College of Global Change and Earth System Science, Beijing Normal University
CanESM2	CCCma	Canada	Canadian Centre for Climate Modelling and Analysis
CCSM4	NCAR	US	National Center for Atmospheric Research
CESM1-BGC	NSF-DOE-NCAR	US	National Science Foundation, Department of Energy, National Center for Atmospheric Research
CESM1-CAM5	NSF-DOE-NCAR	US	National Science Foundation, Department of Energy, National Center for Atmospheric Research
CMCC-CESM	CMCC	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CMCC-CM	CMCC	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CMCC-CMS	CMCC	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CNRM-CM5	CNRM-CERFACS	France	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
CSIRO-Mk3-6-0	CSIRO-QCCCE	Australia	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
FGOALS-g2	LASG-IAP	China	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences
FGOALS-s2	LASG-IAP	China	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences
FIO-ESM	FIO	China	The First Institute of Oceanography, SOA, China

GFDL-CM3	NOAA GFDL	US	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2G	NOAA GFDL	US	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2M	NOAA GFDL	US	Geophysical Fluid Dynamics Laboratory
GISS-E2-H	NASA GISS	US	NASA Goddard Institute for Space Studies
GISS-E2-H-CC	NASA GISS	US	NASA Goddard Institute for Space Studies
GISS-E2-R	NASA GISS	US	NASA Goddard Institute for Space Studies
GISS-E2-R-CC	NASA GISS	US	NASA Goddard Institute for Space Studies
HadCM3	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2-AO	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2-CC	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2-ES	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
INMCM4	INM	Russia	Institute for Numerical Mathematics
IPSL-CM5A-LR	IPSL	France	Institut Pierre-Simon Laplace
IPSL-CM5A-MR	IPSL	France	Institut Pierre-Simon Laplace
IPSL-CM5B-LR	IPSL	France	Institut Pierre-Simon Laplace
MIROC-ESM	MIROC	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC-ESM-CHEM	MIROC	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC4h	MIROC	Japan	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MIROC5	MIROC	Japan	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for

			Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MPI-ESM-LR	MPI-M	Germany	Max Planck Institute for Meteorology (MPI-M)
MPI-ESM-MR	MPI-M	Germany	Max Planck Institute for Meteorology (MPI-M)
MRI-CGCM3	MRI	Japan	Meteorological Research Institute
NorESM1-M	NCC	Norway	Norwegian Climate Centre
NorESM1-ME	NCC	Norway	Norwegian Climate Centre

7. References

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Kharin, V. V., F. W. Zwiers, X. Zhang and M. Wehner (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble. Climatic Change. Vol. 119. No.2. pp 345-357.

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APPENDIX B
Grand River Conservation Authority (GRCA) Hydrology Analysis Data (RSI 2018)

RISK SCIENCES INTERNATIONAL

DATA REPORT

Grand River Conservation Authority (GRCA)

Hydrology Analysis Data

Prepared for:
Matrix Solutions Inc

March 9 2018

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Contents

Risk Sciences International (RSI) provides in this document and attached spreadsheet historical and projected Canadian RCM data for Guelph, ON. No in-depth analysis was requested for this report, however some very basic checks were performed and are included here. Matrix is aware of the use of raw model data and the requirement to correct for any model bias between actual observations and modelled output. Matrix is aware that this request is for a single model run and this projection will vary between runs for the same model and from other regional climate model projections and emission scenarios. CanRCM4 was developed by Environment and Climate Change Canada and is driven by the Canadian General Circulation Model (GCM) CanESM2. These models have been used extensively in climate change modelling research projects.

Outline of Deliverables:

1. Daily TMAX/TMIN/PRECIP from CanRCM4,
2. Using one run, for RCP8.5
3. At the 25km resolution gridpoint representative for Guelph, ON
4. Period of 1981-2100
5. No bias correction for the historical period is performed
6. Data will be supplied in excel format with each line representing a separate day in the full period
7. Map showing the location of CANRCM4 gridpoints and the one selected
8. A quick inspection and note of nearby ECCC observations stations and one station which provides historical normals values for 1981-2010 for comparison

Grid Selection

A representative grid point was selected from the CanRCM4 25km grid. No single point completely covers the urban Guelph location (black dot on image below), so a point immediately west was chosen (circled below). The value displayed represents the 1981-2010 mean annual temperature. This point was selected since it falls, on average, between values from gridpoints surrounding Guelph. Precipitation values are also intermediate for this grid point from all points surrounding. The climate change signal for all surrounding points is very similar, so the point selection would have negligible effect on the climate change projections from this model run.

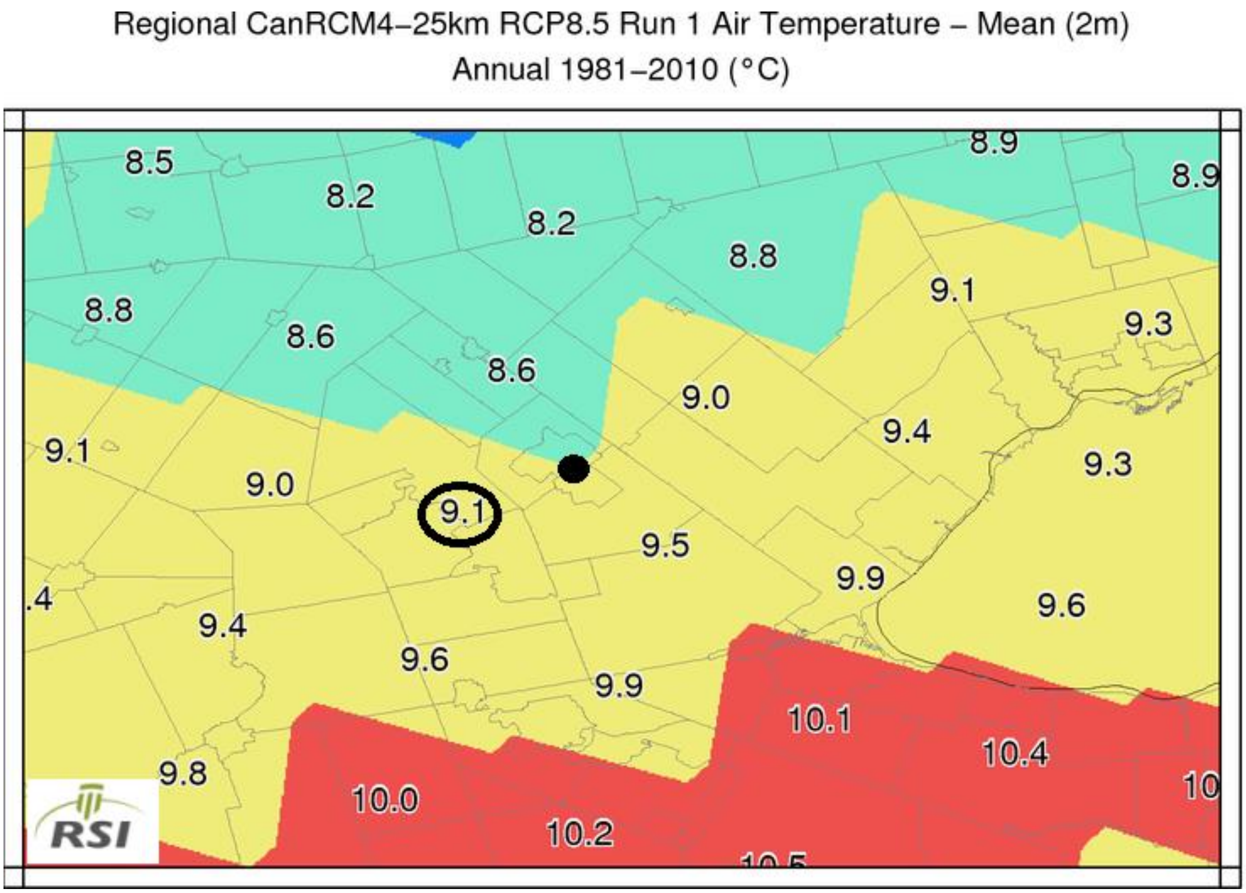

Figure 1: The CanRCM4 gridpoint selected (circled) and Guelph location (black dot).

Basic Model Validation Information

There is no Guelph location with an official climate normals record available from Environment and Climate Change Canada (ECCC) to compare against model output. There is a Guelph observation station (Figure 2, orange circle), but its period of record is not sufficient to calculate a normals value for temperature or precipitation for 1981-2010. All other black circled locations are ECCC stations, but also are of insufficient period to calculate normals. The closest location with a normals value is Fergus Shand Dam, located to the north of Guelph. This location is shown on Figure 2 below.

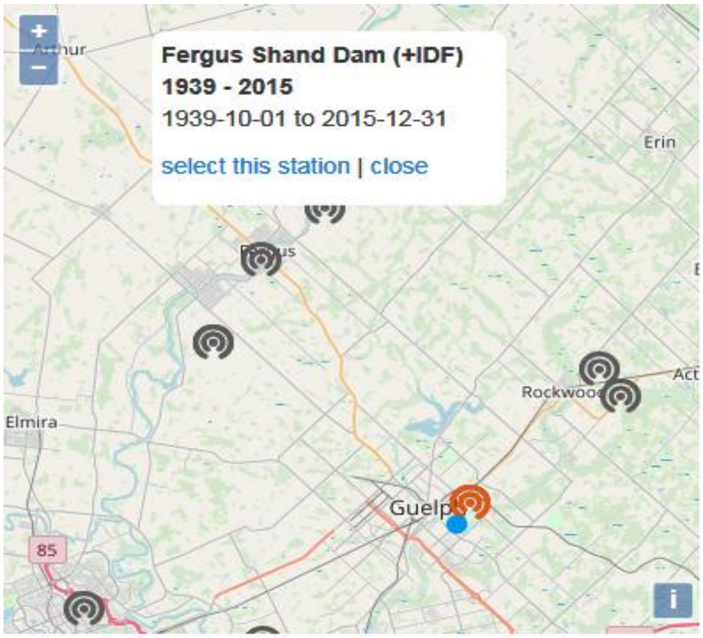

Figure 2: Location of Guelph (blue dot), nearest ECCC station (orange) which has insufficient data, and other ECCC stations with insufficient data. The closest station with sufficient data to calculate a 1981-2010 normal is Fergus Shand Dam as indicated in top centre of figure.

Data from Fergus Shand Dam for 1981-2010

Data from ECCC normals from Fergus Shand Dam for the period of 1981-2010 is shown below for temperature (Figure 3), and precipitation (Figure 4). Source: (http://climate.weather.gc.ca/climate_normals/index_e.html)

1981 to 2010 Canadian Climate Normals station data

Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-7.4	-6.3	-1.9	5.7	12.2	17.5	20.0	19.0	14.9	8.3	2.1	-3.9	6.7	A
Standard Deviation	3.1	2.4	1.9	1.6	2.1	1.4	1.3	1.3	1.4	1.3	1.6	2.8	0.9	A
Daily Maximum (°C)	-3.6	-2.1	2.6	10.4	17.5	22.8	25.2	24.2	19.8	12.7	5.4	-0.7	11.2	A
Daily Minimum (°C)	-11.1	-10.5	-6.5	0.9	6.9	12.2	14.7	13.8	9.9	3.9	-1.2	-7.1	2.2	A
Extreme Maximum (°C)	15.6	12.0	23.9	29.0	32.0	34.0	**35.5**	35.0	35.0	28.9	24.4	17.5		
Date (yyyy/dd)	1950/ 25	2000/ 27	1945/ 26	1990/ 28	2006/ 29	1988/ 25	**1988/ 06**	1948/ 27	1953/ 02	1946/ 06	1950/ 01	1982/ 03		
Extreme Minimum (°C)	**-35.0**	-32.8	-31.7	-18.9	-6.1	-0.6	2.2	-0.6	-5.0	-11.7	-18.3	-34.4		
Date (yyyy/dd)	**1943/ 20**	1948/ 10	1948/ 05	1944/ 01	1966/ 07	1957/ 03	1950/ 16	1942/ 25	1965/ 27	1965/ 29	1958/ 30	1942/ 20		

Figure 3: Fergus Shand Dam – Climate Normals for temperature (ECCC).

1981 to 2010 Canadian Climate Normals station data

Precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Rainfall (mm)	27.8	25.3	36.7	67.9	86.8	83.8	89.2	96.6	93.1	75.6	80.5	34.7	797.8	A
Snowfall (cm)	40.1	30.6	22.9	6.2	0.1	0.0	0.0	0.0	0.0	1.6	12.5	33.9	147.8	A
Precipitation (mm)	67.9	55.9	59.6	74.1	86.9	83.8	89.2	96.6	93.1	77.2	93.0	68.6	945.7	A
Extreme Daily Rainfall (mm)	33.6	42.0	42.4	67.4	87.9	113.5	81.2	**117.6**	105.8	78.7	50.4	39.4		
Date (yyyy/dd)	1993/ 04	2001/ 09	1942/ 16	1991/ 09	1955/ 24	1967/ 10	1987/ 19	**1968/ 05**	1986/ 10	1954/ 15	1992/ 12	1942/ 27		
Extreme Daily Snowfall (cm)	25.4	22.2	22.9	20.8	2.8	0.0	0.0	0.0	1.3	16.5	**45.7**	24.1		
Date (yyyy/dd)	1966/ 22	2006/ 04	1947/ 04	1975/ 02	1940/ 02	1940/ 01	1940/ 01	1940/ 01	1942/ 28	1952/ 19	**1950/ 24**	1968/ 27		
Extreme Daily Precipitation (mm)	33.6	43.2	42.4	67.4	87.9	113.5	81.2	**117.6**	105.8	78.7	61.0	39.4		
Date (yyyy/dd)	1993/ 04	2001/ 09	1942/ 16	1991/ 09	1955/ 24	1967/ 10	1987/ 19	**1968/ 05**	1986/ 10	1954/ 15	1950/ 24	1942/ 27		
Extreme Snow Depth (cm)	44	**54**	52	22	0	0	0	0	0	7	16	39		
Date (yyyy/dd)	2001/ 05	**2001/ 08**	2001/ 06	2001/ 02	1983/ 01	1983/ 01	1983/ 01	1983/ 01	1983/ 01	1997/ 27	2005/ 26	2000/ 24		

Figure 4: Fergus Shand Dam – Climate Normals for precipitation (ECCC).

Comparison with model values against the grid cell for Fergus Shand for the 1981-2010 period shows that CanRCM4 gridcell there (not provided), shows a mean annual temperature of 8.6°C, whereas the observed value at that location from ECCC observations is 6.7°C. This is approximately a two degree warm 'bias' if this point location is considered against the cell value (which represents a 25 x 25 km box). This warm bias is also found regionally for this model for this particular run of the model – it is not simply this selected point.

For precipitation, CanRCM4, like many models produce precipitation on almost every day, but at miniscule amounts which are then generally set to zero if under measurement limits of 1mm. In this case, using the same Fergus gridcell, total precipitation was summed after resetting these very small daily values to zero. For the period of 1981-2010 the mean annual average precipitation at that location was calculated as 855.2mm. The normals value observed at Fergus Shand Dam from the ECCC station is 945.7mm. This indicates a model dry 'bias' of approximately 90mm/yr on average. This dry bias is also found regionally for this model for this particular run of the model – it is not simply this selected point.

The above information indicates that some form of model bias adjustment is most likely necessary for further analysis by Matrix.

These types of biases are commonly found and are correctable prior to applying the model directly in subsequent analysis. This would serve to bring the modelled values much closer to the observed period and subsequently provide better projections of future daily values. Typically such corrections can be made by applying a corrective offset adjustment for temperature, or percentage adjustment for precipitation based on annual, seasonal or monthly factors. No such bias correction has been made on the data provided by RSI.

APPENDIX C
Monthly Change Fields for Selected Global Climate Models

Table C1 Monthly Change Fields for GCMs Selected from Temperature Percentile

Temperature Percentile	MODEL MONTHLY DELTAS (between baseline and 2050s)												
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
5th	FIO-ESM(Run 1)												
	tmean change (C)	2.98	2	2.49	1.86	1.84	1.98	2.17	2.27	1.56	1.72	2.87	3.38
	precip change (%)	-4.22	-3.8	30.03	14.69	1.28	-8.85	-10.57	-10.2	-4.12	1.83	-3.45	-9.66
25th	CCSM4(Run 1)												
	tmean change (C)	3.22	3.78	2.67	2.41	2.22	2.22	3.25	2.97	2.4	1.99	2.84	3.88
	precip change (%)	19.82	21.65	23.18	-1.87	-11.61	-4.2	-11.9	-3.25	-2.87	-0.57	-15.3	23.44
50th	CSIRO-Mk3-6-0(Run 10)												
	tmean change (C)	3.3	4.11	1.96	2.93	3.82	4.08	3.68	4.24	1.72	2.92	2.41	2.77
	precip change (%)	-0.97	30.11	32.59	16.18	19.36	-12.27	1.98	39.74	15.13	-6.28	-3.21	-7.28
75th	CESM1-CAM5(Run 2)												
	tmean change (C)	5.06	7.35	4.15	2.52	2.42	2.73	3.33	3.35	3.24	2.9	2.05	4.52
	precip change (%)	16.55	9.22	35.27	6.7	15.69	12.5	21.87	6.74	-5.33	3.5	3.23	16.9
95th	MIROC-ESM(Run 1)												
	tmean change (C)	5.45	6.66	7.31	4.08	3.37	3.29	3.77	3.68	3.31	3.31	3.89	3.81
	precip change (%)	-5.93	20.23	22.47	29.06	14.79	-10.13	-4.04	-0.05	4.2	-7.44	7.72	15.48

* annual average may not exactly match monthly average due to rounding and regridding process

Table C2 Monthly Change Fields for GCMs Selected from Precipitation Percentile

Temperature Percentile	MODEL MONTHLY DELTAS (between baseline and 2050s)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5th	IPSL-CM5A-MR(Run 1)												
	tmean change (C)	2.32	2.65	2.71	2.69	2.88	3.16	3.4	3.49	4.08	3.35	3.05	2.3
	precip change (%)	3.71	0.16	18.77	16.08	12.31	-1.32	-19.99	-0.01	-3.45	1.1	-12.75	-12.22
25th	CNRM-CM5(Run 1)												
	tmean change (C)	4.6	3.49	3.39	2.14	2.67	2.52	2.7	3.61	3.51	2.84	2.08	3.84
	precip change (%)	-4.92	14.91	0.01	19.69	10.84	-1.5	-5.73	-0.48	-6.66	11.87	3.15	16.91
50th	NorESM1-M(Run 1)												
	tmean change (C)	3.99	4.28	2.12	2.06	2.97	2.84	3.37	3.23	2.86	2.67	2.38	4.49
	precip change (%)	3.52	2.39	26.58	6.82	9.42	-8.61	14.09	11.76	-6.05	8.19	-5.61	27.97
75th	ACCESS1-3(Run 1)												
	tmean change (C)	3.22	3.06	3.84	2.63	2.68	2.45	3.08	3.43	2.95	4.44	3.32	4.15
	precip change (%)	20.97	15.61	12.2	4.43	18.91	4.54	-0.67	-1.23	-0.87	16.31	10.71	22.1
95th	CMCC-CESM(Run 1)												
	tmean change (C)	3.52	2.9	3.32	3.79	2.21	2.92	2.44	2.32	2.92	2.51	2.15	3.23
	precip change (%)	18.89	18.58	25.31	30.84	11.82	3.7	4.37	6.25	7.92	11.58	15.12	11.51

* annual average may not exactly match monthly average due to rounding and regridding process